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Waste Minimization Audit Report: Case Studies of Minimization of Solvent Waste from Parts Cleaning and from Electronic Capacitor Manufacturing Operations

Jacobs Engineering Group, Inc., Pasadena, CA

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WASTE MINIMIZATION AUDIT REPORT

CASE STUDIES OF MINIMIZATION OF SOLVENT WASTE FROM PARTS CLEANING AND FROM ELECTRONIC CAPACITOR MANUFACTURING OPERATIONS

by

Jacobs Engineering Group Inc.
Hazardous and Toxic Materials Division
Pasadena, California

Contract No.: 68-01-7053, WA #46

Project Officer

Harry Freeman
Thermal Destruction Branch
Alternative Technologies Division

HAZARDOUS WASTE ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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To promote waste minimization activities in accordance with the national policy objectives established under the 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act of 1976 (RCRA), the Hazardous Waste Engineering Research Laboratory (HWERL) of the USEPA Office of Research and Development has undertaken a project to develop and test a waste minimization (WM) audit procedure.

As part of this project, a total of 6 WM audits were carried out in four separate facilities. This report presents the results of an on-site WM audit performed at an electronic capacitor manufacturing facility for solvent wastes. The report also describes the WM audit procedure as it has developed from the initial (pre-project) sequence of steps, to the modified (post-project) sequence that reflects the experience gained during this HWERL project.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes reponsibly and economically.

This report describes several studies carried out to identify waste minimization opportunities for solvent waste streams from an electronic capacity manufacturing facility. It will be useful to individuals interested in hazardous waste minimization technology and technologies.

For further information, please contact the Alternative Technologies Division of the Hazardous Waste Engineering Research Laboratory.

Thomas R. Hauser
Director
Hazardous Waste Engineering Research Laboratory

Abstract

To promote waste minimization activities in accordance with the national policy objectives established under the 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act of 1976 (RCRA), the Hazardous Waste Engineering Research Laboratory (HWERL) of the USEPA Office of Research and Development has undertaken a project to develop and test a waste minimization (WM) audit procedure.

As part of this project, a total of 6 WM audits were carried out in four separate facilities. This report presents the results of an on-site WM audit performed at an electronic capacitor manufacturing facility for solvent wastes. The report also describes the WM audit procedure as it has developed from the initial (pre-project) sequence of steps, to the modified (post-project) sequence that reflects the experience gained during this HWERL project.

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1. INTRODUCTION

1.1 Background and Report Organization

The national policy objectives established under the 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act of 1976 include the goal of reduction or elimination of hazardous waste as expeditiously as possible. To promote these activities, the Hazardous Waste Engineering Research Laboratory (HWERL) of the U.S. EPA, Office of Research & Development has undertaken a project to develop and test a waste minimization audit procedure. It is envisioned that such a procedure would be useful to the generators of hazardous waste in their search for waste minimization alternatives.

The potential value and desirability of conducting waste audits has been recognized by a number of authors, although different approaches and scope limits have been suggested for audit activities (Fromm and Callahan 1986, Kahane 1986, Pojasek 1986, U.S. Congress 1986, USEPA 1986a). In this HWERL project, a recently developed audit procedure was tested by conducting actual audits in cooperating industrial and government facilities. A total of 6 audits were carried out in 4 different facilities. This initially proposed audit procedure was then modified to reflect insights and experience gained in the field.

Section 2 of this report describes the elements of an overall waste minimization program, of which the audit procedure is an important component. Section 3 deals with the waste minimization audit procedure itself, its development, and its final recommended form. Sections 4 and 5 present the results of the waste audits performed at two separate facilities with operations which generate solvent-based waste. The 4 other audits performed as part of this project are discussed in separate reports.

2. WASTE MINIMIZATION PROGRAM

2.1 Comparable Program Types

Structured programs designed to improve the cost, energy efficiency, environmental, safety or other aspects of an industrial undertaking are not a new concept. During

World War II, the General Electric Corporation developed standardized procurement procedures for reducing product cost without sacrificing functionality. Later, similar procedures were developed and applied to reduce the costs of design and construction projects. This activity, known as value management, value engineering, or value analysis, is currently well established as a government requirement. In fact, it was mandated by the U.S. EPA for construction projects involving waste water treatment plants; a subsequent study of 56 treatment plants showed that cost reduction programs saved $95 million, for a 12 to 1 return on investment (Zimmerman and Hart 1982).

Environmental compliance audits and reviews are also becoming well established and are acquiring the status of the industry norm. The primary objective of environmental audits is to "..determine the status of corporation's compliance with federal, state and local environmental laws and regulations" (Truitt et al. 1983). Additionally, such audits can often provide information for risk assessment and corporate planning.

Energy conservation audits are performed to reduce energy consumption per unit production. It was estimated that energy audits helped save chemical process industries about $1 billion between 1974 and 1979 (Parkinson 1979). Other related structured programs include safety reviews, hazard analyses, or failure mode and effects analyses (Williams 1976). Waste minimization programs can be considered to be in the same category of programs.

The principal objective of a waste minimization (WM) program is to reduce the quantity and/or toxicity of waste effluents leaving the production process in a manner consistent with the goals of protecting human health and environment. Unlike environmental audit programs, a WM program does not seek to determine or improve the regulatory compliance status of a facility. Rather, it is primarily oriented toward producing a set of effective measures to reduce waste generation.

2.2 Waste Minimization Program Organization

Table 2-1 presents a breakdown of WM program elements. In the context of an overall WM program, the waste auditing process (composed of pre-audit, audit, and post-audit phases) follows the program initiation/planning phase. During this initiation/planning phase, the commitment of top management to reduce waste generation must be first established. This is often done with a formal directive signed by the chief executive

TABLE 2-1 WASTE MINIMIZATION (WM) PROGRAM ELEMENTS

Program Phase	Job Plan* Phase	Elements
I. Initiation/Planning		o Secure commitment/authority o Establish goals o Establish organization
II. Pre-audit	Information	o Preparation for the audit o Pre-audit inspection o Data compilation and waste stream selection
III. Audit	Creative	o Facility inspection o Generate comprehensive set of WM options
	Judgement	o Options evaluation o Selection of options for feasibility analysis
IV. Post-Audit	Development	o Technical and economic feasibility analysis
	Recommendation	o Report preparation
V. Implementation		o Selection of options for implementation o Design, procurement, and construction o Startup o Performance monitoring

*term adopted from value management program.

officer of the firm or the chief administrator of a government organization (League of Women Voters 1985). The organizational commitment to start a WM program is often associated with a goal setting process (e.g., DuPont is considering an annual 5% waste reduction goal).

A corporate WM program may be organized in a typical pyramid structure, with command and monitoring functions centered at the corporate level, and implementation responsibility totally delegated to individual plants. A corporate-level independent expert task force may be formed to assist individual plants with setting up and executing their own WM programs.

At the individual plant level, the WM program can follow the scheme successfully used at Union Carbide for energy conservation efforts. At Union Carbide plants, a plant program coordinator is appointed and supported by a committee. The coordinator then selects and oversees individuals in each department who are responsible for devising and/or carrying out WM activities in their respective departments (Williams 1976).

The program planning phase should include selection of audit team(s) to carry out the next program phase. The audit team leader should have a strong technical background, demonstrated problem solving ability, and preferably, experience associated with the relevant process(es). Additionally, the leader should possess strong management and communication skills. It is preferable that the leader, or at least some members of the audit team, not have a strong previous association with the plant, so as to bring a fresh, independent, and unbiased perspective to the audit process. Such outsiders can be independent consultants or qualified personnel from other plants.

The audit team must have access to all required documentation and to a wide variety of plant personnel. During a recent internal workshop on waste minimization conducted by a major U.S. corporation, the participants (mostly environmental affairs managers at individual plants) were asked who should provide support to a waste audit team. The following responses were obtained:

- Raw material suppliers
- QA/QC department
- Outside consultants
- Customer representatives

- Process engineer
- Safety engineer
- Materials engineer
- Foreman
- Plant manager, and
- Purchasing

In short, the organization should be prepared to provide the audit team with access to a wide range of people inside and outside of the firm. The teams employed in carrying out the two pilot audits described in this report were comprised entirely of employees of outside consulting/engineering firms. The composition of the outside audit teams and of the support groups on the facility side is presented in Table 2-2.

The waste auditing process (phases II, III and IV), described in detail in the next section, provides the key input to the implementation phase of the program, i.e., recommendations on which WM measures are to be implemented. Once a decision to proceed with implementation of a specific WM measure is made, subsequent activities follow a well established, conventional pattern. Detailed design follows preliminary design; the procurement effort proceeds through inquiry and definitive bids, bid analysis, and expediting stages; and the construction effort proceeds along the path determined by a detailed schedule and budget. The budget is controlled through estimates of project cost performed at various project stages with an ever increasing accuracy as material and labor requirements become better defined. Startup follows mechanical completion. The final element of the implementation phase is the ongoing performance monitoring in order to ascertain the waste reduction effectiveness of the changes made.

3. WASTE AUDITING

3.1 Waste Minimization (WM) Audit Procedure

As shown in Table 2-1, waste audits are a central part of a WM program. The auditing process is subdivided into pre-audit, audit and post-audit phases. The recommended sequence of steps shown in Table 2-1 (also shown in expanded form in Table 3-1), is based on modifications of the originally proposed sequence which is presented in Table 3-2. Modifications were made to reflect the experience and insights gained as a result

TABLE 2-2 WASTE AUDIT TEAMS AND RESIDENT SUPPORT GROUPS FOR THE TWO PILOT AUDITS AT SOLVENT WASTE GENERATING FACILITIES

Facility S-1 (air base)

A. Outside Audit Team
  - Chemical engineer[1], B.S., 13 yrs experience
  - Chemical engineer, B.S., 6 yrs experience
  - Independent consultant[2], B.S., chemistry, 25 yrs experience

B. Resident Support Team
  - Environmental coordinator
  - Environmental engineer
  - Chemist (materials science group)

Facility S-2 (capacitor manufacturer)

A. Audit Team
  - Chemical Engineer', B.S., 13 yrs experience
  - Chemical engineer, B.S., 6 yrs experience
  - Independent consultant[2], B.S. chemistry, 25 yrs experience

B. Resident Support Team
  - Facilities engineer
  - Environmental coordinator

---

1. Audit team leader.
2. Technical support and review function only.

TABLE 3-1 RECOMMENDED WASTE MINIMIZATION AUDIT PROCEDURE

Program Phase	Activities	Product
Pre-Audit	1. Preparation for the audit	o needs list/inspection agenda
	2. Pre-audit meeting and inspection	o notes
	3. Data compilation and waste stream selection	o facility and process description o waste description o rationale for selection
Audit	4. Audit inspection	o notes
	5. Generation of a comprehensive set of WM options	o list of proposed options with written rationale
	6. Options evaluation	o independent options ratings by audit team and by plant personnel followed by joint review
	7. Selection of options for feasibility analyses	o list of selected options o options interim report
Post-Audit	8. Technical and economic feasibility analysis	o study or budget grade estimates of capital and operating costs; profitability analysis
	9. Final report preparation	o final report with recommendations

TABLE 3-2 INITIALLY PROPOSED WASTE MINIMIZATION AUDIT PROCEDURE

Job Plan Element	Step	
Information phase	1.	Preparation for inspection
	2.	Facility inspection
	3.	Process and waste stream description
Creative phase	4.	Generation of WM options
Judgement phase	5.	Preliminary evaluation and ranking of options
	6.	Presentation, discussion and joint review of options with plant personnel
	7.	Selection of options for feasibility analysis
Development phase	8.	Technical and economic feasibility analysis
Recommendation phase	9.	Final report preparation

of actual audit work. Sections below detail each of the nine steps of the recommended audit procedure shown in Table 3-1.

3.1.1 Preparation for the Audit

The objective of this activity is to gain background information about the facility to be audited. Preparation should include examination of references related to the activities performed at the facility and if available, review of process flow diagrams, heat and material balances, piping and instrumentation diagrams, and all documentation regarding equipment cleaning and waste handling procedures. The result of proper preparation should be a well-defined needs list, inspection agenda, or a checklist detailing what is to be accomplished, what questions or issues need to be resolved, and what information needs to be gathered.

For the two host facilities audited in this report, the needs list (Table 3-3) was provided to the resident support team in advance of the site visit. This improved the efficiency of the site visit since it allowed the facility personnel to assemble the materials needed by the audit team in advance. A more generalized list of documents and information sources is given in Table 3-4.

In the pilot audits of the two facilities, the availability of the requested process documentation varied considerably. While detailed process information was available from the capacitor manufacturing facility (S-2), very little documentation existed or was available at the air base (S-1). To circumvent this problem, the audit team generated a generic specification data sheet for small tanks and degreasers (the most common types of equipment that utilize solvent at the facility). These data sheets were very helpful in obtaining the required information during the pre-audit and audit inspections.

3.1.2 Pre-Audit Meeting

The purpose of this meeting is to become familiar with plant operations and with plant personnel. Initial contacts with plant personnel should include solicitation of their views on the focus and function of the audit. This will help to identify areas of concern to the facility. The information needs defined in the previous step should be

TABLE 3-3 WASTE MINIMIZATION AUDITS - INFORMATION NEEDS LIST FOR SOLVENT STREAMS

---

1. Process Flow Diagrams (PFD's) with Heat and Material Balances (HMB's).
2. Piping and Instrumentation Diagrams (P&ID's).
3. Plot Plan or general arrangement of equipment.
4. Process description (work flow, solution flow, liquid and solid wastes).
5. Composition of baths and makeup water.
6. Quantities and costs of chemicals.
7. Dimensions and operating gallonage of all tanks.
8. Quantities and costs of disposal for all wastes, liquid and solid; frequency of bath replacement.
9. Materials of construction.
10. History of previous waste management projects, and any related documentation.

TABLE 3-4 WASTE MINIMIZATION AUDITS
GENERALIZED LIST OF INFORMATION SOURCES

- Design process flow diagrams (PFD) with heat and material balances (HMB) for process and pollution control systems
- Equipment list
- Piping and instrument diagrams (P&ID)
- Materials application diagrams (MAD)
- Plot and elevation plans
- General arrangement drawings
- Piping layout drawings
- Operation manuals, process descriptions
- Permits and/or permit applications
- Emission inventories
- Hazardous waste manifests
- Annual (or biennial) reports
- Waste assays
- Operator data logs, batch sheets
- Materials purchase orders
- Environmental audit/review reports
- Production schedules
- Organization chart

SAMPLE SPECIFICATION DATA SHEETS FOR COLD TANKS AND DEGREASERS

SOLVENT USER DATA SHEET PAGE 1/3

USER ____________ LOCATION ____________

SERVICE ________________________________

TYPE COLD TANK ____ ________________

VAPOR DEGREASER ____ ________________

OTHER ____ ________________

MANUFACTURER ________________________

CAPACITY, GALLONS ________ MATERIALS OF CONSTRUCTION

WIDTH ________ TANK WALLS ________

LENGTH ________ LINING ________

DEPTH ________ FITTINGS ________

FREEBOARD ________

COVER TYPE ____________ USAGE ____________

AGITATION ____________ CFM / KW ____________

HEATER TYPE ____________ DUTY ____ TEMP.,F ____

COOLER TYPE ____________ DUTY ____ TEMP., F ____

WATER SEPARATOR ____________ SIZE ____ FLOW ____

HOOD / LOCATION ________________________

SKETCH

SOLVENT USER DATA SHEET

PAGE 2/3

SOLVENT USED	1	2	3
MIL SPECIFICATION	________	________	________
DESCRIPTION	________	________	________
	________	________	________
DUMP BATCH SIZE			
GALLONS, SOLVENT	________	________	________
GALLONS, WATER	________	________	________
DUMP FREQUENCY			
SOLVENT	________	________	________
WATER	________	________	________
DUMP INDICATOR			
ACIDITY	________	________	________
TEMPERTURE	________	________	________
OTHER	________	________	________
DISPOSAL METHOD			
SOLVENT	________	________	________
WATER	________	________	________

NOTES

SOLVENT USER DATA SHEET PAGE 3/3

	1	2
PARTS DESCRIPTION		
ITEM		
SIZE		
BASE/SURFACE MATERIAL		
DEPOSIT THICKNESS		
DEGREE OF CLEANLINESS		
ORGANIC DEPOSIT TYPE		
DRAWING COMPOUND		
CUTTING OILS/COOLANT		
GRINDING LUBRICANTS		
BUFFING COMPOUNDS		
HEAT TREAT QUENCH OIL		
RUST PROTECTION OILS		
LUBE OILS		
HYDRAULIC FLUIDS		
PAINT		
ADHESIVES		
INKS		
OTHER		
INORGANIC DEPOSIT TYPE		
MOISTURE/WATER		
HEAT TREATING SCALE		
WELDING SCALE/BURNS		
RUST/CORROSION		
OXIDATION/TARNISH		
WATER SCALE		
SOLDER FLUX/RESIDUES		
OTHER		

NOTES

discussed here and hopefully fulfilled. A guided tour of the facility also should be taken.

At this initial visit, the groundwork for a successful working relationship with facility personnel must be laid. The importance of a cooperative attitude and active involvement by host facility personnel to the success of the audit process must be stressed. The initial point of contact at the facility (Plant Manager, Environmental Coordinator, etc.) must be enlisted as a "Product Champion" for the program before the audit commences. He/she must be encouraged to relay the message of cooperation and involvement to others at the facility.

3.1.3 Data Compilation and Waste Stream Selection

At this point, it is recommended that a written description of the facility, process or operation, and of waste streams be developed based on the compiled data. The description should encompass:

- o Facility location and size;
- o Description of operations or process(es) of concern, including diagrams necessary to detail the pertinent aspects of waste generation; and
- o Waste stream(s) description centering on sources and current methods of management. This information should be supplemented with summaries of generation rates, compositions, and raw material and disposal costs.

Descriptions of facility, process, and waste stream(s) for the two pilot audit facilities are given in Sections 4 and 5. Such descriptions summarize, in essence, all the pertinent information acquired.

If the waste streams were not selected during the pre-audit meeting or the initial inspection, then they should be selected now. Selection should be based on discussions with plant personnel and on the independent assessment of the project team. The criteria used for selection must include at a minimum:

- Waste compositions
- Quantities of waste generated
- Degree of hazard (toxicity, flammability, corrosivity)

- Method and cost of disposal
- Potential for minimization and recycle
- Regulatory issues (e.g., compliance status or problems)

For the audit reports dealing with solvent waste, selection could not be performed until after the site visits. This was due to the diverse nature of the operations and sources that generate solvent waste. For the two case studies dealing with cyanide wastes (discussed in a companion report), stream selection was not a required step. Focusing of the audits on a particular type of waste (cyanides) simplified the selection process, since electroplating was the only cyanide waste producing operation performed at the audited facilities.

3.1.4 Audit Inspection

In the course of pre-audit phase activities, a general understanding of the process facility operations and, most importantly, of waste sources was established. Also, the waste stream selection process will have been finalized and the information summarized in a written description of the facility, process, and waste stream(s).

With the needed understanding of the process and focus in place, the audit inspection can now be conducted. Typically, the inspection would focus now on the select aspects of the operation identified through the pre-audit activities. The governing objective is to evolve a fuller understanding of principal and secondary causes of waste generation and to cover the items missed in the pre-audit stage.

The audit inspection is the ultimate step in the information gathering process. The following guidelines have been formulated as a result of the work performed in this project:

1. Have an agenda ready--this should cover all points that still require clarification following the pre-audit work.

2. Schedule the inspection to coincide with the particular operation that is of interest, e.g., make-up chemical addition, bath sampling, bath replacement, etc.

3. Obtain permission to interview the operators, shift supervisors, and foremen directly. Listen attentively and do not hesitate to question more than one person if the answer is not forthcoming. Try to assess the operators' and their supervisors' awareness of waste generation aspects of the operation. Note their familiarity (or the lack thereof) with the impacts their operation may have on other operations, e.g., the effect of routing spent stripping solutions into the existing waste water treatment plant.

4. Obtain permission to photograph the facility. Photographs are especially valuable in the absence of plan layout drawings. Many details can be captured in photographs that otherwise could well be forgotten or inaccurately recalled at a later date.

5. Observe the "housekeeping" aspect of the operation. Check for signs of spills or leaks. Ask to visit the maintenance shop and inquire about their problems in maintaining the equipment leak-free. Assess the over-all cleanliness and order of the site.

6. Assess the level of coordination of environmental activities between various departments.

It is of benefit during the planning and conduction of the audit inspection itself to mentally "walk the line" from the suspected source of waste generation to the point of exit, be it a treatment unit, storage facility, or haulage to off-site TSD facilities. The audit inspection must result in a clear understanding of waste generation causes.

3.1.5 Generation of WM Options

Up until this point, the audit process has been mainly oriented toward information gathering and organization. These activities should have established a thorough understanding of the origins of waste generation and of the process or facility operations in general. The audit activity is now ready to move into the creative phase.

The objective of this step is to generate a comprehensive set of WM options. This may take the form of a "brainstorming" session involving audit team members or through separate efforts by individual members. A combination of these approaches was found to be of value during the pilot audits. In this stage of the audit process, it is important to generate as large a number of options as possible. The WM measures currently in place in the audited facility should also be listed. This knowledge often leads to formulation of additional options and provides a valuable insight for the subsequent option evaluation step.

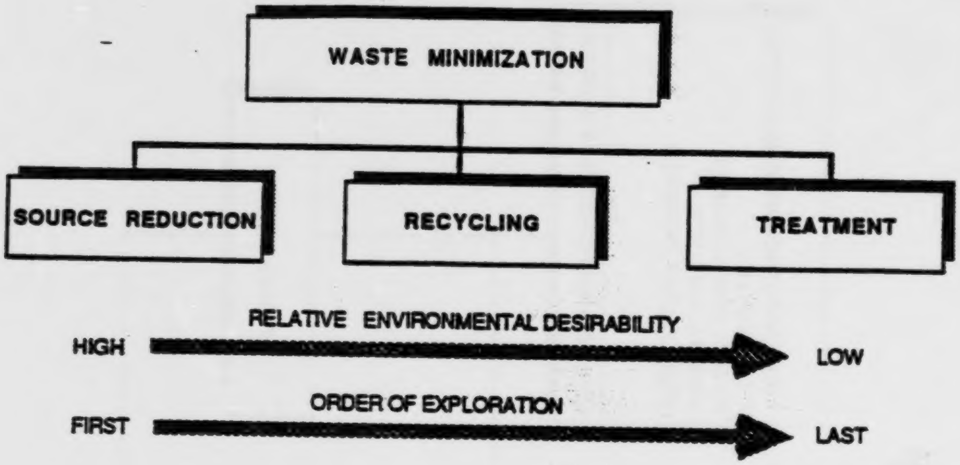
Options generation should generally follow the hierarchy in which most of the effort would focus on source reduction, followed by recycling, followed by treatment. Such a hierarchy of effort stems from the environmental desirability of source reduction over recycling, and of recycling over treatment. Current EPA-proposed definitions of waste minimization and of key waste minimization terms are given in Figure 3-1. A generalized guide to various source reduction elements is given in Figure 3-2. For discussion of the terms and examples illustrating each element, the reader is referred to the EPA support document for the 1986 Report to Congress on Waste Minimization (USEPA 1986b).

To generate options, it is often necessary to examine the technical literature. The reference section of this report provides the listing of sources consulted for solvent waste reduction. Options can also be formulated through discussion with manufacturers of equipment or suppliers of process input materials. A third way to generate options is through the use of a checklist. A checklist suitable for solvent wastes was formulated based upon the audit work performed at the two facilitites and is presented in Table 3-5.

The result of the WM options generation step should be a report in which each option is identified, together with a brief description of the rationale for its inclusion. Included should be such items as effectiveness, applicability, operating constraints, and any other information regarding the potential success or failure of the option. For examples of these reports, refer to Sections 4.6 and 5.6

3.1.6 Options Evaluation

Each of the options postulated in the preceeding step must undergo a preliminary (mostly qualitative) evaluation. The objective of this evaluation is to weed out the measures that do not merit additional consideration and to rank the remaining measures in the order of their overall desirability.



WASTE MINIMIZATION

The reduction to the extent feasible of hazardous waste that is generated or subsequently treated, stored or disposed of. It includes any source reduction or recycling activity undertaken by a generator that results in either (1) the reduction of total volume or quantity of hazardous waste or (2) the reduction of toxicity of the hazardous waste, or both, so long as such reduction is consistent with the goal of minimizing present and future threats to human health and environment (EPA's Report to Congress, 1986).

SOURCE REDUCTION

The reduction or elimination of waste generation at the source, usually within a process (op.cit).

RECYCLING

A material is "recycled" if it is used, reused, or reclaimed (40 CFR 261.1 (c) (7)). A material is "used or reused" if it is either (1) employed as an ingredient (including its use as an intermediate) to make a product; however a material will not satisfy this condition if distinct components of the material are recovered as separate end products (as when metals are recovered from metal containing secondary materials) or (2) employed in a particular function as an effective substitute for a commercial product (40 CFR 261.1 (c) (5)). A material is "reclaimed" if it is processed to recover a useful product or if it is regenerated. Examples of recovery of lead values from spent batteries and regeneration of spent solvents (40 CFR 261.1 (c) (4)).

TREATMENT

Any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste or so as to render such waste non-hazardous, safer for transport, amenable for recovery, amenable for storage or reduced in volume. Such term includes any activity or processing designed to change the physical form or chemical composition of hazardous waste so as to render it non-hazardous (RCRA, Subtitle A, Section 1004(34), PL-98-616).

Figure 3-1Components of waste minimization, their hierarchy and definitions.

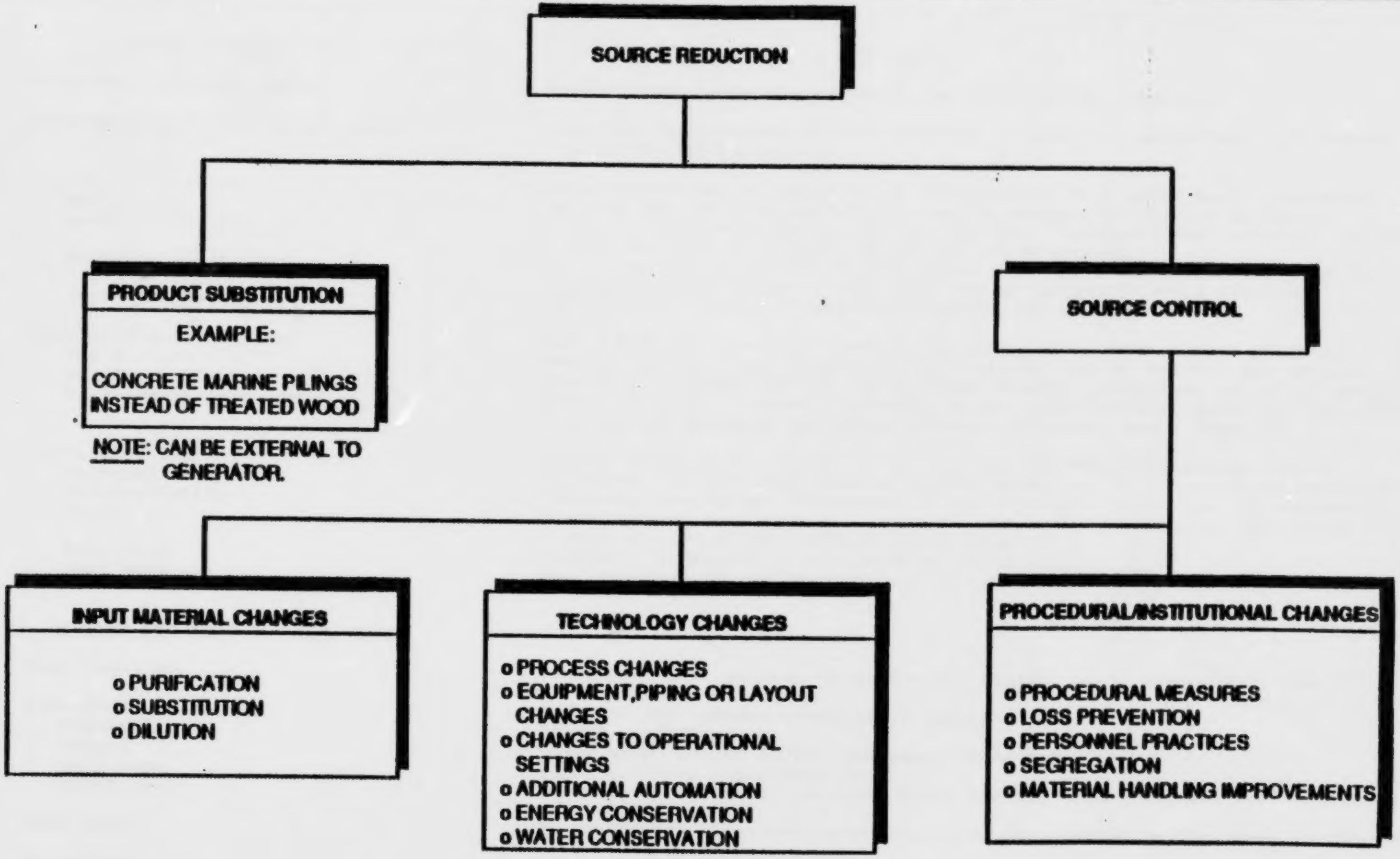

SOURCE REDUCTION
PRODUCT SUBSTITUTION
EXAMPLE:
CONCRETE MARINE PILINGS INSTEAD OF TREATED WOOD
NOTE: CAN BE EXTERNAL TO GENERATOR.
SOURCE CONTROL
INPUT MATERIAL CHANGES
o PURIFICATION
o SUBSTITUTION
o DILUTION
TECHNOLOGY CHANGES
o PROCESS CHANGES
o EQUIPMENT,PIPING OR LAYOUT CHANGES
o CHANGES TO OPERATIONAL SETTINGS
o ADDITIONAL AUTOMATION
o ENERGY CONSERVATION
o WATER CONSERVATION
PROCEDURAL/INSTITUTIONAL CHANGES
o PROCEDURAL MEASURES
o LOSS PREVENTION
o PERSONNEL PRACTICES
o SEGREGATION
o MATERIAL HANDLING IMPROVEMENTS

Figure 3-2 **Elements of source reduction**

TABLE 3-5 SOURCE REDUCTION OPTIONS CHECKLIST FOR SOLVENT WASTES

GENERAL OPTIONS	COMMENTS
Alternate cleaning agents	- Possible replacements include steam and alkaline cleaners.
Alternate paint stripping agents	- Possible replacements include caustic, cryogenics, abrasives, and thermal paint stripping methods.
Equipment cleaning	- Uncontrolled use of solvent for cleaning can be a major waste generator.
Dedication	- Reduces the need for equipment cleaning between batches of product.
Quality control	- Reduces the generation of off-spec batches. Equipment that produces off-spec material must be cleaned before it can be reused.
Mechanical cleaning	- Use of wipers to remove deposits from tank walls can reduce the need for cleaning with solvent. Pipelines can be "pigged" before flushing.
Inert blanketing	- Prevents the drying of materials inside the equipment.
Equipment modification	- Can reduce the need for cleaning or reduce the waste volumes produced.
Bag filters	- Retain less material than cartridge filters. Can be cleaned and reused.
Metal mesh filters	- Can be back-washed during system flush thereby generating no filter waste.
Clean-in-place systems	- Often designed to recycle cleaning agent. High pressure spray systems often eliminate the need for using solvents to remove heavy deposits.
Waste handling	- Proper handling is crucial to the success of recycling solvent waste.
Segregation	- Increases the liklihood that a solvent waste can be successfully recycled.
Standardization	- Increases the amount of recyclable waste thereby improving the economics.
Reuse	- Dirty solvent can often be reused in less critical cleaning operations or be used as part of the product formulation.
Recycling	- Requires the use of a continuous or batch still.
Heat Recovery	- Many solvents can be used as fuel in industrial boilers/furnaces.
OPTIONS FOR COLD CLEANING TANKS	
Tank location	- Tanks near heat sources or drafts can exhibit large evaporative losses.
Tank lids	- Frequent use reduces evaporative losses.
Removable	- Seldom used if heavy.
Hinged	- Often used. Piston effect can cause emissions.
Roll type	- Best. Disturbs vapor zone least.
Water seal	- Used with chlorinated solvent. Water quality should be routinely monitored.
Tank vents	- Excessive use increases emissions. Flow rate should be less than 50 cfm/ft2.
Parts handling	- Proper handling can extend solvent life and reduce losses.
Precleaning inspection	- Parts should be relatively dry. Excessive water can lead to acid formation when chlorinated solvents are used.
Entrance/exit speed	- Avoid speeds greater than 11 feet per minute to avoid drag-out of vapor.
Part drainage	- Parts should be properly racked so that solvent drains freely.
Rack maintenance	- Cracks can drag-out solvent and corrosion can contaminate the solvent.

TABLE 3-5 SOURCE REDUCTION OPTIONS . . . continued

Cleaning efficiency	- The greater the efficiency, the more parts cleaned per volume of solvent.
Degree of agitation	- Can be increased by installing a pump/jet, a mixer, or an ultrasonic unit.
Two-step counter-current sequence	- Allows a higher degree of spent solvent contamination to be reached.
Emulsifiers	- Provides additional cleaning action by dissolving grease and soil.
Vapor degreaser	- Can clean at much higher contamination levels than can cold cleaning tanks and provides a much better cleaning action.
OPTIONS FOR VAPOR DEGREASERS	
Operation	
Heat input	- If too high, will increase solvent loss to the atmosphere.
Cooling water temperature	- Solvent vapor will not be recovered if too high and undue condensation of moisture from the atmosphere will occur if too low.
Parts spraying	- Spraying parts above the vapor line bypasses the emission control equipment.
Overloading	- Overloading collaspes the vapor zone which causes air to be drawn into the unit. Solvent loss occurs as the zone reforms and the air is expelled.
Maintenance	
Leaks	- Cooling coil/steam leaks can introduce excessive water into the unit.
Water separator	- Failure to routinely purge (remove water) can lead to acid formation.
Stabilizer level	- Stabilizers are added to chlorinated solvent to prevent acid formation.
Cross-contamination	- Trace amounts of different solvents can lead to acid formation.
Sludge removal	- Routine removal reduces the amount of solvent absorbed by the sludge and the potential for acid formation.
Solvent recovery	- Vapor degreasers can be operated as a still to recover solvent.
Modification	
Freeboard height	- Increased height can reduce solvent vapor loss due to turbulence/drafts.
Freeboard chillers	- Can be used to create a blanket of cold air which suppresses vapor loss.
Silhouette entries	- Reduce the open area of the unit thereby reducing vapor loss.

It is recommended that the evaluation process be performed by two independent groups or individuals, e.g. by the audit team and by the host facility personnel. Getting and keeping the facility personnel actively involved in the evaluation process is an important tool in maintaining their interest in the overall waste minimization process.

The evaluation should include, at a minimum, consideration of the following aspects:

- Waste reduction effectiveness (i.e., reduction of waste quantity and/or toxicity)
- Extent of current use in the facility
- Industrial precedent
- Technical soundness
- Cost
- Effect on product quality
- Effect on plant operations
- Implementation period and
- Resources availability and requirement

The reviewers should discuss each proposed measure one by one in each area given above. After discussion, each measure would be rated qualitatively on scale of 0 (low) to 10 (high) in terms of:

- Waste reduction effectiveness
- Extent of current use in the facility and
- Future application potential (a qualitative measure of probability that the option will be implemented, and which is dependent on the last 7 of the 9 elements listed above).

The rating system is in essence an activity management tool for the evaluation process. It forces the participants to follow a defined pattern of steps and provides a framework for resolving difference of opinions. The product of the evaluation process is the orderly listing of each measure, along with the associated rating in each of the three categories. The reader is referred to Tables 4-3 and 5-4 for examples.

3.1.7 Selection Options for Feasibility Analysis

Following the evaluation (i.e., rating each option for its waste reduction effectiveness, extent of current use in the facility, and future application potential) by two independent groups or individuals, the ratings are compared and discussed in a joint meeting. The objective of this meeting is to develop ratings which are mutually acceptable. While the ratings obtained by the two independent teams will differ, the differences are likely to be small for the most part. Major differences that signify vastly different perceptions must be reconciled during this meeting.

The product of the meeting is a WM options list with revised ratings. The final ratings are then used to calculate two valves called the Current Reduction Index (CRI) and the Future Reduction Index (FRI):

CRI = score for effectiveness X score for extent of current use/10

FRI = score for effectiveness X (10 - score for extent of current use) X score for future application potential/100

The CRI is a qualitative measure of the amount of waste already reduced by the facility due to a given technique. The FRI is a qualitative measure of the amount of waste that can be reduced by implementing a given technique or option.

Selection of options for additional feasibility evaluation is based on the FRI value. The higher the value, the more attractive the option as a candidate for additional consideration. Also to be considered for selection are measures that have a low FRI value simply because the extent of their current use is high. Such measures might be considered for additional implementation since their usefulness has been proven. However, their effect on additional waste volume or toxicity reduction is probably relatively low.

The number of measures promoted to the feasibility evaluation stage depends on the time, budget, and resources available for such study.

3.1.8 Analysis of Technical and Economic Feasibility

The specific WM options selected in the previous step must be analyzed to determine the equipment and materials that would be required. A preliminary process flow diagram, heat and material balance, and equipment list is developed. Equipment is sized and budget quotes with preliminary vendor information obtained. In cases involving a large number of equipment items and substantial amounts of piping and instrumentation, factored estimation techniques can be used.

In retrofit cases, it may be enough to prepare sketches of the proposed equipment installation (e.g. bag filter for recovering stripping solution), in order to obtain sufficient resolution of detail needed for a budget-grade estimate. The complexity of the preliminary engineering work required may vary considerably. It would probably be worthwhile to allow prospective vendors to inspect the site (although it has not been done in any of the audits performed for this project). Calculations have to be made to ascertain the viability of proposed option(s). For example, mathematical modeling of various solvent loss paths (evaporation, forced evaporation, drag-out, and contamination) was performed to assess the effectiveness of various control options. This above effort yields a summary of capital and operating costs for the option. The estimates are typically of study-grade (±30%) accuracy.

Following development of capital and operating costs for each option, the analysis is focused on an estimation of profitability. For this project, a simple payback period method was used considering the rather moderate levels of capital investment involved and the lack of "borderline" cases. More sophisticated methods (net present value or internal rate of return) would be used for more capital-intensive cases. Additional information on the estimation of profitability of WM measures can be found in a recent publication by Fromm and Butler (1986).

3.2 Observations Made During The Audits

Some of the most important lessons learned in the pilot audits relate to the human element of the audit process, i.e., to the interaction between the audit team and host facility personnel. It obviously is important that host facility personnel become and remain active participants throughout the audit process. Some non-technical skills of the audit team personnel, and particularly of the audit team leader were found to be extremely important here.

The audit team leader must be an effective and aggressive communicator, as well as a technical expert, because the team leader must play an important role as a facilitator for the audit team and host facility personnel alike. In one case, a reserved and low key attitude and behavioral style by the audit team initially led to a passive and relatively disengaged stance by the host facility personnel.

3.2.1 Pre-Audit Phase

The experience at the various audit sites indicates that the availability and quality of information varies significantly. It is important to make allowance for this possibility and to have a fall-back position. For example, if a piping and instrument diagram (P&ID) is not available, often times a piping layout plan will be. Similarly, if the information is not available from the facility, it does not mean that it cannot be obtained.

Much information is available from outside sources such as trade journals and vendors, e.g., the costs of bath make-up chemicals or the design of the process equipment. If information is truly needed but is not readily available, it can be obtained with proper initiative and ingenuity. This can adversely affect project cost and schedule, however. In this light, it is important that only the information truly required to understand the process, to allow for delineation of waste sources and current waste management techniques, and to characterize waste generation quantitatively should be sought. Requesting unnecessary information burdens both the provider and user (auditor) and slows down the work.

The importance of the pre-audit activities, particularly the pre-audit site visits, were revealed as being extremely important in facilitating the audit process. At a facility where the audit team spent a little more time getting to know the host facility staff and how their organization functioned, the audit process moved more smoothly. The audit team found it easier and faster to acquire needed data because they knew better where (e.g., from whom) to obtain what data. Likewise, because they knew the operation and the people a little better, the level of cooperation by plant staff was improved.

When the generation of a particular type of waste is due to a diverse range of operations, then the selection of waste streams plays a crucial role in the focus of the audit and the types of options that can be generated. For example, two different audit approaches were initially considered for the facilities generating solvent waste. The two approches were:

- Characterize the major solvent using operations or processes in terms of type of solvent used, rate of solvent usage, waste generation rate, and other pertinent characteristics. This compilation would then be used to investigate waste minimization options such as standardization (reducing the number of different types of solvent employed), consolidation (reducing the number of end use points), reuse (using spent solvent in succeedingly less critical cleaning applications), and substitution. Following these options, the issue of recycling would be addressed.

- Audit a small select group of operations involving major types and uses of solvents. Waste minimization options to be considered would include physical modification of the equipment and changes in operational procedures.

Both approaches were used in the solvent waste audits. For facility S-1, an air base consisting of both military and civilian operations, the second approach was deemed more practical by the audit team and facility personnel. The first approach would have required an extensive review of solvent usage at the base. To obtain this information, many differrent functional organizations would have to be contacted since individual groups at the base are responsible for only a few operations. The ability to consolidate cleaning operations or reuse solvents (an objective of the first approach) would therefore by greatly diminished by this division of responsibility. Therefore, it was felt that restricting the audit to selected operations would produce the most implementable options. The most promising options then could be applied to similar facility operations by the base staff.

For facility S-2, the first approach was used. The second approach would have been very narrow in range since the facility performs many one of a kind operations. Physical modifications recommended for one operation would most likely not be applicable to other operations. Since the waste volumes generated by any one process and by the facility overall were relatively small, the audit's main focus was placed on segregation and recycling as opposed to modification and reduction.

3.2.2 Audit Phase

The pilot studies experience led to a modification of the initially proposed audit method. The modified approach requires host facility personnel to independently develop ratings of each of the waste reduction options under consideration. The audit team's ratings of the options and the host facility's independent ratings can then be reviewed and reconciled in a group session. The initial approach of having the host facility personnel merely review and discuss the audit team's ratings following the presentation of the option ratings resulted in a relatively casual and less involved behavior by the host facility staff.

Another observation is that the evaluation process may require several iterations, as the terms "waste reduction effectiveness", "extent of current use" and, especially, "future application potential" require assimilation by the host facility personnel. At both audits, a tendency was observed on the part of host facility reviewers to be fairly lax in the rating process. The audit team leader must convey the importance of this step to the team i.e., that the ratings will be used as the basis screen for the various measures.

3.2.3 Post-Audit Phase

The pilot studies revealed the importance of how audit results (options and recommendations) are presented to plant personnel. In one case, when audit team members were extremely comprehensive and detailed in describing and explaining the rationales for the options under consideration, plant personnel began to lose interest in the deluge of information. It also was found that Good Operating Practices (GOP) recommendations must be presented with tact. In one case, host personnel initially considered a number of GOP recommendations as trivial, and even a little insulting ("don't you think we know all that already"). However, this reaction changed considerably when the estimated cost savings for strictly adhering to these GOP measures were provided.

In summary, a WM audit (and a WM program as a whole), requires effective communication and human interaction, as well as technical insight and engineering skills on the behalf of the audit team members. A successful WM audit program requires success in both the technical and human relations areas.

4. AUDIT REPORT FOR FACILITY S-1A/B

4.1 Facility Description

Facility S-1A/B, located in Southern California, is a major aviation, industrial, and seaport complex supporting anti-submarine aircraft, helicopters, and aircraft carriers of the Pacific Fleet. Facility S-1A operations are mostly performed by military personnel, while facility S-1B operations are performed by civilians.

4.2 Equipment Layout Description

There are over 100 solvent end use points in the entire base. Solvent is used in many servicing operations, especially parts degreasing and paint stripping. Due to the magnitude and diverse nature of the operations performed, base personnel were asked if the audit could be limited to a few operations that were representative of base operations overall.

Ten stations were investigated during the initial audit visit and are described in the sections that follow. Stations consisted of single tanks (in the case of paint stripping or vapor degreasing), or tanks in series (in the case of a sequential cleaning operation). The main criteria in establishing what constituted a station was based on the system's functionality and degree of interdependence with other systems. Since many different stations were audited initially, as opposed to auditing one given facility or operation, the description of equipment layout was included in the process description.

4.3 Process Description

4.3.1 Facility S-1A, Building 1454

The facilities at Building 1454 service many different types of naval aircraft and are under military command. Aircraft parts are routinely degreased or stripped of paint in cold tank operations. Two stations were investigated during the initial audit.

Station #1 - Cold Cleaning Tank

Parts, such as wheels or brake drums, are allowed to soak for twenty minutes in a covered tank of PD-680 (Stoddard solvent) to remove grease. The cover is of hinged design and incorporates a vent along the back edge. The vent is usually turned on after the cover is raised so as to reduce worker exposure to fumes. To ensure adequate cleaning of the parts, the operator often must use a brush to scrub the parts clean. Once cleaned, the parts are placed on a screen inside a separate rinse tank and rinsed with water using a hose. When finished, the water supply is shut off and the part allowed to dry.

Station #2 - Epoxy Stripping Tank

Station #2 is very similar in design to Station #1. MIL-R-81294, an alkaline methylene chloride/phenolic compound/chromate based paint stripper, is used for stripping epoxy-based paint from aircraft parts. The parts are placed inside the tank and allowed to soak until the paint becomes loose. The parts are then scrubbed manually with a brush, rinsed with water in a separate rinse tank, and allowed to dry.

4.3.2 Facility S-1A, Building 767 - "Power" Plant

Operations at Building 767 include the maintenance and cleaning of aircraft engine parts and are under military command. Several solvents such as PD-680 (degreasing), AMS 3065 (a solvent cleaner used for finishing), and Penair M5704 (a solvent emulsion cleaner consisting of aromatic and paraffinic solvents) are used to remove grease, rust protection oils, and hydralic fluids from parts. The facility houses thirteen small cleaning tanks that can be used individually or in series. All of the tanks have pneumatic hinged covers and mechanical agitation systems. Also located in the facility is a Recyclene X35 distillation unit. The unit was being installed at the time of the audit, and was not yet operational.

Cleaning begins by placing the parts into a heavy metal basket. The basket is then placed onto a segmented roller conveyor, parts of which are designed to drop down into the tank when the lid is closed. A mechanical agitation system raises and lowers the basket inside the tank. When the lid is raised, the basket rises and the parts drain. Roller conveyors, built into the lids of each tank and along the sides, allow the baskets to be moved freely between various tanks. Two stations, engine parts cleaning (six tanks) and ball bearing cleaning (three tanks), were investigated during the initial audit.

Station #3 - Engine Parts Cleaning

The engine parts cleaning line consists of six tanks set up in the following sequence: unheated PD-680, unheated PD-680, empty, heated alkaline cleaner, heated water, and heated Penair M5704 (an aromatic solvent). Cleaning begins by placing dirty parts into a basket and lowering the basket into the first tank of PD-680. After this initial cleaning, the parts are moved to the second tank of PD-680. After cleaning with PD-680, the parts are conveyed to the heated water tank for rinsing and then to the heated alkaline cleaning tank. Alkaline cleaning is used to remove the film of oil that remains after cleaning with PD-680. This cleaning is followed by a water rinse and then cleaning in the heated Penair M5704 tank. Penair M5704 removes any remaining traces of contamination and displaces any water remaining on the parts. After removal from this tank, the parts are allowed to air dry.

Station #4 - Ball Bearing Cleaning

The ball bearing cleaning line consists of three tanks set up in the following sequence: unheated PD-680, unheated PD-680, and unheated AMS 3065. Cleaning begins by placing the dirty ball bearings into a basket and lowering the basket into the first tank of PD-680. While the basket is being mechanically agitated, an installed pump and filter (20 micron) continuously removes particles from the solvent bath. After this initial cleaning, the parts are moved to the second tank of PD-680. This tank also has pump around but with a 10 micron filter installed. After cleaning with PD-680, the parts are cleaned in a tank of AMS 3065. This solvent is used to remove traces of the PD-680 cleaning solvent and any remaining traces of contamination such as fingerprints.

4.3.3 Facility S-1A, Building 801 - Ground Support Equipment Shop

The facilities at Building 801 are involved in the repair and maintenance of a ship's ground support equipment. When personnel from visiting ships require the use of the facility, separate work areas are provided. One station was investigated during the initial audit. Building 801 is under military command.

Station #5 - Cold Cleaning Tank

Each work area has its own 10 to 12 gallon cold degreasing tank which is filled with PD-680 II (Stoddard solvent with a flash point greater than that of PD-680). Each unit is designed with a safety lid that closes in the event of a fire and a small electric pump. Parts to be cleaned are placed inside the tank and washed using a jet of solvent provided by the pump. When clean, the parts are removed and allowed to dry. The facility has four units available for use.

4.3.4 Facility S-1B, Building 472

Operations in Building 472 include cleaning and stripping of paint from very large objects or pieces of equipment. The facility maintains many large (3,400 gallon) tanks that contain PD-680, epoxy paint stripper, alkaline cleaners, acid cleaners, and water rinses. Parts are moved from one tank to another by means of a computerized overhead hoist system. The facility is under civilian command.

No mechanical lids are utilized on the tanks (except for the vapor degreasers). Air emissions are controlled by means of a horizontal push-pull air curtain system across the tops of the tanks. On some paint stripper baths, a water seal is used (i.e., a layer of water floats on top of the solvent). Located at the back of the facility are two solvent cleaning spray booths for use on small items. These booths are currently being equipped with a carbon adsorption system to control air emissions. Four stations (the four major solvent using operations), were investigated during the initial audit.

Station #6 - Tank C1-1

Tank C1-1 is a vapor phase degreaser with spray wand attachment. Parts are lowered into the tank and degreased in the 1,1,1-Trichloroethane vapors. Additional cleaning action can be provided by means of the installed spray unit. Heating is supplied by 15 psig steam which maintains the solvent boiling at 160°F. The degreaser is provided with a cooling water coil followed by a refrigerated coil located around the wall perimeter above the vapor zone. Return temperature on the cooling water is approximately 100 °F. The refrigerated coil maintains a blanket of cool air above the vapor/air interface and suppresses emissions. Since the operation of the refrigerated coil causes water in the air to condense and mix in with the solvent, a water separator is provided. Currently, plywood panels are utilized as a lid on the unit.

Station #7 - Tank C1-5

Tank C1-5 is used for stripping epoxy-based paint from parts. The tank contains 3,400 gallons of Turco 5351 (a slightly alkaline methylene chloride-based paint stripper that contains phenolic and chromate compounds). A six-inch water seal is used to suppress emissions of methylene chloride. The acidity of the stripper bath is routinely monitored and adjusted by adding sodium hydroxide.

Station #8 - Tank C1-7

Tank C1-7 is used as a de-sealant and occasionally as a paint stripper. The tank contains 3,400 gallons of BNB 3536 and is equipped with a push-pull air curtain system.

Station #9 - Tank C1-8

Tank C1-8 is used as a carbon deposit and paint remover. The tank contains 3,400 gallons of MIL-C-19853 (an alkaline methylene chloride/chromate based paint stripper). A six inch water seal is used to suppress emissions of methylene chloride.

4.3.5 Facility S-1B, Building 35 - Bearing Shop

The Bearing Shop is involved with the cleaning and assembly of precision mechanical devices and is under civilian command. The tanks used are very similar to the tanks used in Building 767, except that no alkaline cleaners or water rinses are used. One station was investigated during the initial audit.

Station #10 - Bearing Cleaning

Cleaning begins by placing the parts into a heavy metal basket that is sent through a conveyorized solvent spray system. PD-680 is used in this unit. Next, the basket is lowered into a cold cleaning tank of PD-680 and BNB 2020 (a solvent emulsion cleaner) and mechanically agitated. The cleaning tank is equipped with a roller conveyor that lowers down into the bath and automatically closes the lid. When cleaning is complete, the basket is raised up out of the tank, allowed to drain, and then conveyed to a second tank of PD-680. Following the second tank, two additional cleaning tanks that contain PD-680 may be utilized. The last cleaning operation occurs in a small vapor degreaser that utilizes Freon 113 to remove the traces of PD-680 solvent.

4.4 Waste Steam Description

4.4.1 Building 1454

Station #1 - Cold Cleaning Tank

A batch of solvent in the tank lasts approximately one month based on the normal throughput of parts requiring cleaning. When the solvent requires replacement, one drum (55 gallons) of used solvent is removed from the tank and two drums of fresh solvent are added. The difference in the amounts of solvent removed and added is due to the effects of evaporation and drag-out. According to the operators, drag-out can be as high as two to three ounces of solvent per part. The drum of used solvent is kept segregated from other solvent wastes and is transferred to the Public Works Center (PWC) Hazardous Waste Collection, Holding and Transfer (CHT) Facility. Rinsewater, which is uncontrolled and free-flowing, is discharged to the wastewater treatment facility.

Station #2 - Epoxy Stripping Tank

During normal usage, the stripper solution remains active for approximately 1.5 months. At that time, the spent paint stripper is discharged to the wastewater treatment facility via the industrial sewer and the tank is refilled with fresh stripper.

4.4.2 Building 767 - "Power" Plant

Station #3 - Engine Parts Cleaning

The only solvent waste disposal information available for this operation is that 5 gallons of PD-680 solvent are usually removed from each tank 3 to 4 times a year. Cleaning efficiency is maintained by dumping a small amount of dirty solvent from the tank and adding fresh. When the facility reaches full operational status (the facility is currently operating at reduced loads), it is intended that the two tanks of PD-680 will operate in counter-current fashion. That is, dirty solvent will be removed from the first tank and solvent from the second tank will be used as make-up. All additions of fresh solvent will be to the second tank. This mode of operation should reduce the amount of solvent waste generated from these two tanks. The tank of Penair M5704 has not been in operation long enough to determine solution replacement frequency.

Station #4 - Ball Bearing Cleaning

Waste generation rates for Station #4 could not be determined due to lack of reliable data.

4.4.3 Building 801 - Ground Support Equipment Shop

Station #5 - Cold Cleaning Tanks

Based on the average workload of the facility, each cold tank generates seven to eight gallons of solvent waste per six week period. This equates to a 55-gallon drum of waste solvent being disposed of every two to three months. Waste generation rates can be much greater if the operator feels that the cleaning ability of the solvent has lessened to an appreciable degree, or if the pump unit becomes inoperable or clogged due to solids. When this occurs, the dirty solvent is drained from the unit into the storage drum and replaced with fresh solvent. Solvent is also drained from the unit if the work area is no longer needed.

4.4.4 Building 472

Station #6 - Tank C1-1

The vapor degreaser generates approximately 400 gallons of solvent waste per year. This waste is in the form of a sludge that collects in the boiling sump of the unit and on the steam heating coils. Solvent contamination is indicated when the solution boiling temperature exceeds 165°F. This waste is removed by the chemical handlers and delivered to the PWC/CHT facility. During routine operation, wastewater is discharged from the unit by way of the water separator. It is estimated that seven gallons per day of water are discharged by the unit (one shift, unit at idle with cover on). This water contains traces of the solvent 1,1,1-TCE and other chemicals (added to the solvent as stabilizers). Discharge is to the PWC Industrial Waste Treatment Facility.

Station #7 - Tank C1-5

Plant personnel indicated that the stripper bath would be dumped when they felt that the stripping action of the bath diminished to an appreciable degree. No stripper solution has been discharged from the tank in the last three and a half years and the activity of the bath was reported as being adequate.

Station #8 - Tank C1-7

The contents of the tank are dumped one to two times per year depending on the facility workload. Disposal is performed by the chemical handlers..

Station #9 - Tank C1-8

The contents of the tank have only been dumped once in the last five to six years. The tank currently processes 2,000 parts per week, which is reported to be a comparatively low work load.

4.4.5 Building 35 - Bearing Shop

Station #10 - Bearing Cleaning

All of the tanks utilizing PD-680 solvent are arranged in a countercurrent configuration. Parts are first cleaned in a tank of dirty solvent and then in tanks of progressively cleaner solvent. When dirty solvent from the first tank is disposed, solvent from the next tank is used as make-up. This sequence proceeds down the line with fresh solvent only being added to the last tank. Since ball bearing cleaning is a critical operation, the amount of dirt or grease in the "dirty" solvent is relatively low. Therefore, most of this solvent was at one time redistributed to other users who did not require as high a degree of cleaning. No Freon 113 is disposed of from the vapor degreaser. Instead, a constant make-up of approximately 13 gallons per day is required due to evaporation losses.

4.5 Current Waste Management Profile

At facility S-1B, the procurement of solvents used for cleaning begins with the production controllers. Each shop employs a production controller whose job is to insure that all operations run smoothly. When a tank of solvent needs to be replaced because its cleaning efficiency has lessened, the production controller contacts the chemical handlers (base employees) to remove the waste solvent. The chemical handlers drum the waste and take it to the Public Works Center (PWC) Hazardous Waste Collection, Holding, and Transfer (CHT) Facility. For Facility S-1A, military personnel remove and drum the spent solvent. They then contact the PWC for pick-up and transfer of the waste to the CHT facility.

When enough waste has been collected at the CHT facility, the Defense Reutilization and Marketing Office (DRMO) is contacted. DRMO arranges for disposal (landfilling) or treatment of the waste by an outside contractor. For waste materials such as dirty Stoddard solvent, off-site treatment usually consists of solvent recovery. Recovered materials are not returned to the facility for reuse, since the materials seldom meet military specifications.

Treatment at PWC is applied to industrial sewer waste, which may contain non-recyclable solvent wastes such as methylene chloride based paint strippers. Most of the non-recyclable solvent wastes are believed to be directly discharged to the industrial sewer for treatment, as opposed to being drummed for landfilling. Treatment of the waste consists of acid neutralization and phenol oxidation. The ultimate fate of the solvent components in the waste is unknown.

A less frequently used waste management option is the direct exchange of waste between production controllers. Instead of being disposed, relatively clean spent solvent can often be used in less demanding cleaning applications. Such an arrangement was reported as occurring at one time between two production controllers (one in the Bearing Shop and the other unknown), but it is not now being practiced. No organized efforts have been undertaken at the facility for coordinating this type of activity.

4.6 Postulated Waste Minimization Options

After reviewing the station descriptions, four stations were selected for a more detailed analysis. The stations selected were Station #1 - Cold Cleaning Tank, Station #4 - Ball Bearing Cleaning, Station #6 - Vapor Degreasing, and Station #7 - Epoxy Paint Stripping. These stations represent a fair cross-section of the types of activities that occur at the base. Waste minimization options, both existing and proposed, are discussed in the following sections.

4.6.1 Station #1 - Cold Cleaning Tank

Using information supplied by the operators, the magnitude of solvent losses due to various operations was estimated. Broken down into discrete operations or steps, sovlent loss occurs when:

- the lid is opened and solvent vapors escape;
- the vent is turned on and fresh air is drawn into the tank replacing solvent-saturated air;
- the parts are removed and solvent is carried out;
- the lid is closed and air leakage occurs due to convection through the vent system.

Each month, approximately one drum (55 gallons) of solvent is removed from the tank and disposed of. Since the total make-up of clean solvent is 110 gallons, 55 gallons of solvent is lost through the above operations. It is estimated that 5 percent of the solvent loss is due to opening the lid, 67 percent is due to operating the vent, 21 percent is due to carry or drag-out, and 7 percent is due to air leakage. Control methods currently in full or partial use include:

o Frequent use of the tank lid.

Station #1 utilizes a hinged type cover to suppress solvent air emissions. During the facility audit, the cover was in place.

- Check vent flows and minimize use time.

Operators are instructed to turn on the vent system whenever the tank is opened. Venting draws the solvent vapors away from the opening and hence protects the worker from exposure. At the same time, venting increases the rate of solvent evaporation from the tank and is the leading cause of solvent loss. Proper equipment design and operation should provide adequate worker protection, while not unduly increasing solvent air emissions. To achieve these goals, several measures can be taken.

A standard rule of thumb is that ventilation systems should be sized for 50 cubic feet per minute (cfm) per square foot of open area (Durney 1984). For Station #1, the flow rate should be approximately 1500 cfm. A check of the vent flowrate is recommended using the standard Pitot tube method. Next, the ventilation system should be checked to ensure that operation of another vent (Station #2) does not cause disturbances inside the closed tank. Finally, operators should be equipped with cleaning brushes and be trained in ways to minimize the amount of time required for cleaning and using the vent system. Properly designed and well maintained cleaning brushes reduce the time required for manually scrubbing the parts. The less time spent scrubbing, the less time spent using the ventilation system. Another measure would be to instruct operators to immediately close the tank and shut off the vent after removing a part. Parts should be rinsed with water after Station #1 has been shut down and not before.

New control methods considered for Station #1 include:

- Convert from a hinged-type to roll-type cover.

Hinged covers create a piston effect when closed, which can force solvent vapor out of the tank. A roll type cover slides across the top of the tank and therefore disturbs the vapor layer less. Roll type covers should be located below the vent pick-up point. This reduces turbulence inside the tank when the vent is in use, prevents the continued disturbance of the vapor layer once the cover is closed, and assures complete closure. Since Station #1 already has a cover and vent system installed, the cost of conversion could be prohibitive and the net benefit marginal.

- Design tank for closed scrubbing.

Tanks designed for closed scrubbing allow an operator to manually clean parts without the need for opening the lid or cover. Existing tanks can be retrofitted by replacing the cover with a plexiglass or Lexan plastic section that includes arm holes and gloves. The clear secton allows the operator to see into the tank and the gloves provide mobility while maintaining a closed system. The major obstacle to this method is the possible inability of designing a working system into the existing tank (the system must be designed with worker comfort and safety in mind at all times). An alternative solution would be to replace the existing tank with a new "closed" system.

- Allow parts to drain adequately.

It is estimated that 21 percent of the solvent loss from the tank is due to solvent liquid drag-out. Operators reported that at least 2 to 3 ounces of solvent are removed form the tank when parts are taken out. Previous studies have indicated that the amount of liquid carried out on a part can range from 8.0 to 24.0 gallons per 1000 square feet of surface for a cup-shaped part that is very poorly drained (Durney 1984). This equates to approximately 1.0 to 3.0 ounces of solvent per aircraft wheel. For a part that was well drained, the amount of liquid dragged-out would range from 0.4 to 0.8 gallons per 1000 square feet. This represents a 90 to 98 perent reduction in solvent loss.

One of the reasons that solvent loss is so high, or that the parts are poorly drained, is that the removal of parts from the tank tends to be an awkward operation. The operator must bend down, pick up the part, allow it to drain, and then carry it over to the rinse tank. Since the parts are heavy, very little time is allowed for drainage. Parts with complex shapes and recesses should be allowed to drain for a minimum of 15 seconds. During this time, the part should be rotated or revolved to facilitate drainage. To eliminate the need for holding the full weight of the part during drainage, a rack or grate should be installed inside the tank. The purpose of the rack is to provide a rest area for the part while the operator allows it to drain.

- Increase solvent cleaning efficiency.

The amount of solvent waste produced can often be reduced by increasing the cleaning efficiency of the system. As an example, most solvents used in cold cleaning applications can still clean at oil or grease levels reaching as high as 10 percent. However, any solvent film left on the part will also contain this same percentage [illegible] oil or grease which can interfere with subsequent operations. To ensure a low level of contamination on the part, many facilities replace solvent when the degree of contamination reaches 1 or 2 percent.

For non-critical cleaning applications, it was initially assumed that the level of contamination in the tank would reach a very high level. Subsequent estimates indicated that for Station #1 such an assumption is wrong. The degree of contamination before disposal is only 1 to 2 percent. The current criterion for replacement is not so much final cleanliness as it is the time it takes for the solvent to dissolve the grease. Solvent is usually replaced when the operator notices that a part is taking too long to clean by soaking. The solution to this problem is to provide some form of agitation. A viable method would be to install a mixer or pump and jet unit inside the existing tank.

A commonly used way to increase cleaning efficiency is to employ a two-step counter-current cleaning operation (a wash-rinse sequence). Parts are initially washed in a tank of dirty solvent, followed by rinsing in a tank of clean solvent (existing tanks can be modified by welding in a center divider). The tank of dirty solvent removes the bulk contamination and reduces the load on the clean tank. When the dirty solvent requires replacement, solvent from the clean tank is used as make-up. Fresh solvent is then added to the clean tank. This assures that the parts are always subjected to a clean solvent rinse. Provided the current degree of solvent contamination is allowed to reach a high level, then the use of a two-step counter-current cleaning sequence will only reduce waste marginally.

Another way of increasing the cleaning efficiency of Stoddard solvent is by adding emulsifiers to the solvent. This method is commonly used whenever a water rinse follows the use of Stoddard. Emulsifiers help prevent dissolved soils from redepositing on the surface of the cleaned part and therefore allow a much higher soil load to be reached before solvent replacement is required. Another benefit is that the emulsifer aids in the penetration of impacted soils so that the need for manual scrubbing is often reduced or eliminated. An obstacle to using emulsifiers or modified Stoddard solvent at Station #1 is that the material may not meet military specifications.

- Use alternate cleaning agents.

Station #1 is involved in the cleaning of parts removed from aircraft. Cleaning is performed to make the job of servicing and inspection easier for personnel. Therefore, critical cleaning of the parts is not required and the potential for substituting alternate cleaning agents for PD-680 exists. Alternate cleaning agents could include alkaline cleaners, steam, or newly developed organic solvents. One such organic solvent, Citrikleen, is reported to be easily recyclable and biodegradable (Penetone Corp. 1986). It has been used on military ground support equipment with success, but has not yet been tested on aircraft parts or against military specifications. A substitute for which military specifications are believed to exist is steam cleaning. Steam cleaning has proven to be very effective at cleaning construction and transit equipment. The obstacle to using alternate cleaning agents is that they may not meet all specifications or may not yet have been fully tested for approval.

4.6.2 Station #4 - Ball Bearing Cleaning

Waste generation rates for Station #4 could not be quantified due to the lack of reliable data. However, the mechanisms for solvent loss should be very similar to those discussed for Station #1. Control methods currently in full or partial use at Station #4 include:

- Frequent use of the tank lid.

Station #4 utilizes a hinged type cover to suppress solvent air emissions. During the facility audit, the cover was in place. Operators are properly instructed that the cover is to be closed whenever the tank is not in use.

- Design tank for closed scrubbing.

All tanks used at Station #4 are designed to scrub or agitate the parts in the solvent bath while the tank lid is closed. When the lid is raised, a roller conveyor track rises up out of the tank which allows a basket of parts to be rolled on. As the lid closes, the roller track and basket drop down into the solvent bath. The basket is then lowered and raised repeatedly inside the tank while the lid is closed. This operation provides agitation, which assists in the cleaning of the parts.

- Check vent flows and minimize use time.

See previous discussion for Station #1.

- Limit entrance/exit speeds.

Just as hinged covers can create a piston effect when raised or lowered, so can the work items. Entrance speeds should never exceed eleven feet per minute or undue vapor loss can occur (ASTM 1976). To ensure that this criterion is met, the pneumatic system should be modified to allow for control of entry immersion speed. Another important item is that the cross-sectional area of the work item or basket should not exceed fifty percent of the tanks open top area (Smith 1981). Since the roller conveyor is designed to drop down into the tank, use of a smaller basket may only provide a marginal reduction in emissions.

- Allow parts to drain adequately.

Solvent loss due to drag-out appears to be high. The basket/roller conveyor system can retain a large amount of solvent since the conveyor has large surface areas that are poorly drained. Rather than immerse the entire roller conveyor segment into the solvent, a better design would rely on raising and lowering the basket inside the tank using an overhead crane system. In addition, roll-type covers would be more appropriate with this arrangement. The cost of modification of the existing equipment may be prohibitive, however.

Drag-out reduction methods based on the current design of the system include allowing the parts ample time for draining over the tank, and providing a way of collecting and returning the solvent that drips on the roller conveyor segment downstream of the tank. If ample room exists inside the tank, then the parts should be allowed to drain inside the tank with the lid closed. This would probably require a slight modification to the controls or control settings of the pneumatic system. Installing a drip recovery system would require some minor piping work, since the roller conveyors downstream of the tank are designed with closed bottoms already equipped with removable plugs.

New control methods considered for Station #4 include:

- Convert from a hinged-type to roll-type cover.

Station #4 currently employs pneumatically operated hinged covers. These covers are specially designed with roller conveyors built into them. This allows items to be easily transferred across the top of any closed tank in the line. Since Station #4 already has a cover and vent system installed, the cost of conversion could be prohibitive and the net benefit marginal.

- Two-step counter-current cleaning.

Station #4 is an ideal candidate for conversion to a two-step counter-current cleaning operation (see process description under Station #1 - Increase solvent cleaning efficiency). Both tanks of PD-680 cleaning solvent employ filter and pump assemblies. By installing some piping and a three way valve, all changing of solvent can be done easily using the existing pumps. By implementing a two-step cleaning operation, it is estimated that the volume of solvent waste can be reduced by 40 to 50 percent.

- Use alternate cleaning agents.

Station #4 is involved in cleaning of ball bearings removed from aircraft engines. Bearings are critical components and the cleaning operation must not affect the bearings in any way. Therefore, rigorous testing would be required to find a viable substitute for PD-680.

4.6.3 Station #6 - Vapor Degreasing

Solvent losses from the vapor degreaser occur by way of air emissions, saturation of the water that must be continuously removed from the unit, and by way of the solvent-laden oil sludge that must be occasionally removed from the unit. Waste minimization measures focus on the ways to reduce these emissions from the unit and on the ways in which the solvent quality can be maintained. By maintaining solvent quality, the need for replacement is reduced, along with the amount of waste produced.

Contamination of solvent usually occurs from drag-in of water, solvent, or aqueous cleaner from previous cleaning operations, failure to remove condensed atmospheric moisture, and failure to remove sludge that collects inside the unit during routine cleaning operations. When contaminants are allowed to accumulate for an extended period of time, the potential for the solvent breaking down and forming acid increases. When a vapor degreaser goes acid, time consuming and expensive measures are required to return the unit to a usable condition.

Water entering the vapor degreaser can form minimum boiling azeotropes with the solvent. Since these azeotropes have a boiling point lower than that of either water or solvent alone, they can lead to increases in solvent vapor loss (the control equipment can be less effective). In addition, water can deplete the stabilizer in the solvent which increases the liklihood of acid formation. Excessive moisture in the unit is evidenced by white cloud-like vapors that float around the cooling coils.

Waste minimization options currently employed at Station #6 to their fullest or partial extent include:

- Frequent use of the vapor degreaser lid.

Lids on vapor degreasers can reduce solvent loss by 24 to 50 percent. Facility personnel reported that they have had much trouble with previous covers but that a new stainless steel roll-type cover would be installed in the near future.

- Increase freeboard height.

Freeboard is defined as the distance from the vapor/air interface to the top of the tank. Station #6 has a freeboard ratio (freeboard height divided by width) of about 1.5 Early designs called for a freeboard ratio of 0.5. By increasing the ratio to 0.75, a 27 to 46 percent reduction in air emissions can be achieved (Durney 1984). An additional 39 percent reduction can be achieved by increasing the ratio to 1.0. This is especially recommended in facilities with air turbulence problems. Since the ratio for Station #6 exceeds 0.75, additional increase appears unwarranted.

- Install a freeboard chiller.

Station #6 has a freeboard chiller installed. This chiller cools the air above the systems primary condenser coil and creates a blanket of cool, heavy air. Reductions in solvent evaporation loss by as much as 60 percent have been reported for typical vapor degreasers (Durney 1984). A drawback is that much more water is introduced into the tank and special water removal equipment is required.

- Spray parts below the vapor line.

When spray wands are employed (Station #6 has a spray unit), all spraying should be performed below the solvent-air interface. Spraying above the interface defeats the operation of the control equipment. In addition, spray units should be designed to provide a very coarse spray or jet as opposed to a finely divided spray mist. Operators reported that they always spray below the interface and that the unit is designed to produce a fluid stream instead of a fine mist.

- Check parts entering the degreaser.

Parts entering the degreaser from previous cleaning operations should be checked to see that they do not carry an undue amount of water or cleaning solution into the degreaser. Another source of water would be carryover of water-soluble cutting oils. Operators reported that most parts enter the degreaser dry.

- Check the cooling water temperature and flow.

To ensure the control of solvent vapors from the unit, the flow rate of cooling water is usually maintained so that its exit temperature is in the range of 90 to 100°F. When water flows are too high, excessive condensation from the air can occur. The cooling water exit temperature at Station #6 was 100°F.

- Limit entrance/exit speeds.

Entrance and exit speeds should never exceed 11 feet per minute or undue vapor loss can occur. Vapor loss occurs because the part acts like a piston and pushes or pulls the vapor past the control devices and out of the tank. In general, the larger the item, the slower the speed should be.

Another problem is overloading the vapor degreaser. Overloading is a common problem when dealing with items that have very large mass and surface area (Dow Chemical 1985). These items conduct heat so rapidly that they temporarily cause the rate of condensation to exceed the rate of solvent evaporation. This then leads to a collapse or rapid shrinking of the solvent vapor zone. When the vapor zone collapses, air is drawn into the unit. As the part heats up and the vapor zone is re-established, solvent-laden air is expelled from the tank. The solution to this problem is to assure that the object is lowered into the degreaser slowly.

- Allow parts to drain or dry adequately.

In order to reduce dragout, only metal chains or baskets made of light weight, open mesh, non-porous material should be used for holding the parts. Porous materials such as cloth bags or ropes should never be used. Parts should be racked so that condensed solvent can drain back into the unit. For parts with cup-shaped recesses, tilting the part during removal may prove effective. If cleaned parts leave the degreased wet, then a drying period inside of the vapor degreasers freeboard area should be allowed for.

- Maintain rack system corrosion-free.

Cracked or corroded racks can increase solvent drag-out. The small cracks and fissures that occur on the rack hold liquid by means of capillary action. In addition to increased drag-out, corrosion deposits that flake off the rack lead to increased solvent contamination. Therefore, racks should be cleaned regularly so that rough surfaces are not allowed to form. An alternate solution would be to use protective coatings specially designed for rack systems.

- Check for cooling coil or steam leaks.

This should be part of routine maintenance activities.

- Check the water separator frequently.

To reduce the likelihood of acid formation inside the water separator, the layer of water that collects inside the unit should be routinely purged (Durney 1984). With most vapor degreasers, purging is performed by closing the solvent return valve and allowing the water to overflow the drain. When the operator notices that solvent is flowing from the water drain, the return valve is then opened. Since this procedure can lead to large loses of solvent if the operator forgets to open the valve, a spring-loaded fail-open valve should be used. This type valve requires that the operator always be present when the valve is closed. Another recommendation is that the water from the drain be collected in a bucket so that any solvent purged from the unit can be recovered. Recovery would consist of decanting the water layer from the bucket and returning the solvent to the water separator.

New waste minimization options considered for Station #6 include:

- Routinely remove sludge.

Sludge should never be allowed to collect inside a vapor degreaser. Relatively insoluble materials such as dried paint will slowly absorb solvent inside the unit. Metallic fines can catalyze solvent decomposition reactions and lead to acid formation. A metal screen should be place over the work rest area to collect excessive metal fines and nonsolubles (Durney 1984). While this screen will require periodic cleaning, the need for system clean-outs will be reduced and the cleaning efficiency of the solvent will be maintained over a longer period of time.

- Reclaim solvent from sludge.

Instead of directly disposing of the dirty solvent, some operators use the degreaser as a batch still (Dow Chemical 1985). To use the unit as a still, the solvent condensate is rerouted to an external tank or to 55-gallon drums. Boildown is allowed to continue until the level of solvent inside the unit approaches the top of the heating coils or until the level of oil in the sludge reaches 60 to 70 percent, whichever comes first. The solvent/soil mixture remaining inside the unit is then removed and stored until the next boildown operation. (if the oil content is less than 60 percent), or disposed of as hazardous waste.

- o Use alternate cleaning agents.

As discussed before, rigourous testing would be required to find a viable substitute for 1,1,1-Trichloroethane.

4.6.4 Station #7 - Epoxy Paint Stripping

The amount of solvent waste generated by Station #7 is very small and sporadic in nature. This is because the station operates at a workload very much less than its design capacity. Therefore, most of the waste minimization measures are designed to reduce the amount of waste that will eventually be generated when the contents of the tank are replaced.

Contamination of paint stripper usually occurs from drag-in of solvent or aqueous cleaner from previous cleaning operations, or from failure to remove sludge that collects inside the unit. When contamination is allowed to exist for an extended period of time, the potential for methylene chloride breaking down and forming hydrochloric acid increases. In addition to acid formation, sludge leads to a decrease in cleaning efficiency and an increase in the amount of time required or stripping. The reason for this is that methylene chloride type strippers function by causing the paint to absorb solvent and swell, thus breaking the bond of adhesion. When paint remains in the tank for an extended period of time, selective absorbtion of the solvent occurs. This leads to an imbalance in the composition of the stripper and hence reduced stripping effectiveness.

Waste minimization options that are currently in full or partial use at Station #7 include:

- o Evaporation loss control.

Station #7 utilizes a methylene chloride-based paint stripper. Air emissions are suppressed by maintaining a six inch layer of water on top of the paint stripper.

- Check parts entering the tank.

Parts entering the tank from previous cleaning operations should be checked to see that they do not carry an undue amount of water or cleaning solution into the tank. While most water entering the tank will make-up for evaporative losses from the water blanket, an undue amount could lead to the need for removing water from the blanket layer and a possible solvent loss. Operators reported that all parts entering the tank are dry.

- Allow parts to drain adequately.

See previous discussion for the other work stations.

- Maintain rack system corrosion-free.

See previous discussion for the other work stations.

New waste minimization options considered for Station #7 include:

- Properly control the pH of the water blanket.

To help neutralize the hydrochloric acid formed in the stripper, the water blanket is usually maintained in an alkaline state (this only holds for neutral or alkaline methylene chloride-based paint stripper such as that used at Station #7). Buffer salts, such as disodium phosphate ($Na2HPO4$), are employed to control the pH of the water blanket at approximately 10.0 (Durney 1984). Strong alkalies, such as sodium hydroxide ($NaOH$), should not be used since they will cause degradation of the methylene chloride. Station operators reported that they normally use NaOH to control pH. This practice should be discouraged and a more suitable controlling agent should be employed. The effect on parts of using other controlling agents should be investigated.

- Reclaim stripper from spent bath.

Methylene chloride-based strippers work by breaking the bond of adhesion between the paint and the substrate. A major advantage of using a cold stripper (a stripper that is formulated to provide stripping action without the use of heat), is that the stripper remains active regardless of the degree of solids loading (Mazia 1984). Slow-down in activity is usually due to a buildup of solids, which reduces the degree of contact between the stripper and the paint. When the decrease in stripping activity indicates the need for replacement, many facilities decontaminate the stripper by straining it through a screen to remove paint sludge.

Decontamination can be accomplished by adding a small pump and strainer unit to the tank that would continuously clean the stripper bath. This would result in maintaining stripper strength at the greatest possible level and in reducing the amount of sludge requiring disposal (paint that remains in the tank will slowly absorb stripper). Since the daily loading on the stripper tank is very low, a small portable system could be designed for cleaning the tank. This unit could then be used for cleaning stripper tanks located in other buildings.

- Use alternate paint stripping agents or methods.

There are many alternatives to methylene chloride-based paint strippers. Some of the alternatives include use of caustic or water-based paint strippers, cryogenic stripping, use of abrasives, molten salt stripping, and thermal stripping. Since caustic or aqueous acid strippers are very ineffective at stripping properly cured epoxy-based paint, their use cannot be recommended. Cryogenic, molten salt, and thermal stripping methods would also have limited application since they cannot be used on parts that are sensitive to heat or easily deformed due to thermal stress. The only feasible alternative method would be abrasive stripping.

The U.S. Air Force has had much success replacing methylene chloride-based paint strippers with a technique called "Plastic Media Blasting" or PMB (Higgins 1985, Roberts 1985). PMB is a dry paint stripping process that uses recyclable plastic media to remove paint. The method has been used for stripping paint from aircraft fuselage and parts.

4.7 Screening of Solvent Waste Minimization Options

Table 4-1 lists the various waste minimization options noted above for each work station. Each option has been rated on a scale of zero (low) to ten (high) for its waste reduction effectiveness, extent of current use, and future application potential. The

TABLE 4-1 SUMMARY OF SOLVENT WASTE MINIMIZATION OPTIONS FOR FACILITY S-1

Waste Source	Control Methodology	Waste Reduction Effectiveness	Extent of Current Use	Future Application Potential	Current Reduction Index	Future Reduction Index
Station #1 Cold Cleaning Tank	1. Frequent use of the tank lid.	3	10	10	3	0
	2. Check vent flows and minimize use.	7	3	8	2	===> 4
	3. Convert to a roll type cover.	1	0	1	0	0
	4. Design tank for closed scrubbing.	7	0	3	0	2
	5. Allow parts to drain adequately.	3	0	8	0	2
	6. Increase solvent cleaning efficiency.	8	0	4	0	3
	7. Use alternate cleaning agents.	10	0	1	0	1
Station #4 Ball Bearing Cleaning	1. Frequent use of tank lid.	3	10	10	3	0
	2. Design tank for closed scrubbing.	7	10	10	7	0
	3. Check vent flows and minimize use.	7	3	8	2	4
	4. Limit entrance / exit speeds.	2	1	3	0	1
	5. Allow parts to drain adequately.	4	1	8	0	3
	6. Convert to a roll type cover.	1	0	1	0	0
	7. Two-step countercurrent cleaning.	8	0	6	0	===> 5
	8. Use alternate cleaning agents.	10	0	1	0	1
Station #6 Vapor Degreasing	1. Frequent use of the degreaser lid.	5	10	10	5	0
	2. Increase freeboard height.	3	10	10	3	0
	3. Install a freeboard chiller.	7	10	10	7	0
	4. Spray parts below the vapor line.	3	7	10	2	1
	5. Check parts entering the degreaser.	3	7	10	2	1
	6. Check cooling water temperature/flow.	4	7	10	3	1
	7. Limit entrance / exit speeds.	3	5	8	2	1
	8. Allow parts to drain/dry adequately.	3	5	10	2	2
	9. Maintain rack system corrosion-free.	3	5	10	2	2
	10. Check for cooling coil/steam leaks.	3	5	10	2	2
	11. Check the water separator frequently.	3	5	10	2	2
	12. Routinely remove sludge.	4	0	5	0	2
	13. Reclaim solvent from sludge.	8	0	5	0	===> 4
	14. Use alternate cleaning agents.	10	0	1	0	1
Station #7 Epoxy Paint Stripper	1. Evaporation loss control.	5	10	10	5	0
	2. Check parts entering the tank.	3	7	10	2	1
	3. Allow parts to drain adequately.	3	5	10	2	2
	4. Maintain rack system corrosion-free.	3	5	10	2	2
	5. Properly control blanket water pH.	3	0	10	0	3
	6. Reclaim stripper from spent bath.	7	0	7	0	===> 5
	7. Use alternate stripper / methods.	10	0	1	0	1

future application potential is a qualitative measure of how difficult that option would be to implement due to technical and/or financial obstacles. After rating each option, the current and future reduction indices were determined.

Each index is computed on a scale of zero to ten with the value of ten indicating that total elimination of the waste is possible. For each station shown in Table 4-1, the highest future reduction index has been marked by an arrow.

For Station #1, the most effective methods would be to check the vent flow and minimize use time, increase the cleaning efficiency of the system, and allow all parts to adequately drain. Increasing the cleaning efficiency would probably require the installation of an agitation unit, while adequate part drainage would require the installation of a drain board or shelf inside the tank. Facility personnel indicated that they would recommend use of a closed tank as an effective method.

Control methods for Station #4 include two-step counter-current cleaning, checking vent flows and minimizing use time, and adequately draining parts inside the closed unit. To achieve increased cleaning efficiency, the use of a two-step countercurrent cleaning sequence is recommended. Equipment required for this modification would consist of some additional piping and valves.

Ways to reduce solvent waste from Station #6 include reclaiming the solvent from the sludge and routinely removing sludge from the tank. Removal of sludge will require the installation of a screen inside the unit. For Station #7, reduction methods include reclaiming of the stripper from spent baths and proper control of the pH. To reclaim stripper, the procurement of a small portable pump and filter unit is recommended. Reclaiming should be performed on a regular basis and the equipment can be used for reclaiming other cold stripper tanks located at the facility.

4.8 Feasibility Analysis of Selected Waste Minimization Options

Following discussion with facility personnel, several of the options described above were selected for further investigation, based on their high future reduction index. Additional information was obtained from further searches of the available literature and from contact with equipment vendors. The measures to be evaluated in further detail include: use of a closed tank and increasing the cleaning efficiency of Station #1 by increasing the degree of agitation; increasing the cleaning efficiency of Station #4 by employing a two-step counter-current cleaning sequence; reclaiming solvent from spent 1,1,1,-TCE at Station #6 by using the degreaser as a still; and continuous filtering of stripper solution at Station #7. Measures that involved changes in operating procedures only were not considered for additional analysis.

4.8.1 Station #1 - Closed Tank

Retrofitting the existing tank to allow the operator to clean parts while the tank lid remained closed would require custom modification of the tank. In addition, most closed tanks are small because the use of gloves fixed to the tank lid limits the reach of the operator. Reviews of information obtained through contacts with equipment suppliers revealed that most closed tanks are used in the electronics industry where the parts being cleaned are small and easily handled. The cleaning of large and heavy aircraft parts in a manually operated closed system does not appear feasible.

Rather than modify the existing tank, a more viable solution would be to install a mechanically agitated closed lid tank similar to the tanks used at Station #4. Another suggested option would be to replace the existing tank with a small vapor degreaser. Many small units are competitively priced compared to mechanically agitated units. Both of these options would require extensive investigation to justify replacement of the existing tank. Therefore, these methods are recommended for study at the time when the existing tank needs to be replaced.

4.8.2 Station #1 - Increased Agitation

Many different ways exist to increase the degree of agitation inside a tank of liquid. Options include the use of ultrasonic units, mechanical mixers, or pump and jet units. For Station #1, only the use of a pump and jet unit would be practical.

Vendors pointed out that the cost of an explosion-proof ultrasonic unit would be prohibitive and that the potential for causing a fire would be great (ultrasonic units can generate heat in the liquid). Use of a mechanical mixer is not practical due to the physical layout of the tank. Most units are designed to agitate the contents of a round tank with a height to depth ratio of one to one. The contents of Station #1 approximate the shape of a large flat slab. Another problem would be the physical presence of the mixer blade inside the tank which could cause damage to the parts.

The pump and jet manifold arrangement would consist of two jet-sparge pipes running the length of the tank, a strainer to remove solid particles that might plug the orifices, a seal-less magnetic drive pump with explosion-proof motor, and some miscellaneous valves and fittings. The two pipes would be located on opposite sides of the tank so as to crease a rolling turbulence in the bath. Operation of the system with the lid closed should not lead to an increase in air emissions. The operator would have to be instructed that the system was intended for use only when a part was inside the tank and the lid was closed.

The cost for modifying Station #1 is shown in Table 4-2. Annual costs for operating the equipment have been excluded since they are believed to be secondary in magnitude to materials and labor. Also excluded are any savings in annual labor costs due to the need for less waste handling. Assuming that the amount of oil in the solvent can be increased from the current estimate of 2 percent to the future estimate of 8 percent before disposal is required, the amount of virgin solvent required and spent solvent disposed of each year will decrease by 495 gallons.

Based on a cost of $1.25 per gallon for virgin solvent and a credit of $0.52 per gallon for waste solvent (information supplied by facility personnel), the annual savings would be $360 resulting in a payback period of 8.0 years. Since the payback period exceeds the required hurdle rate of 3 years, modification of Station #1 cannot be justified at this time. If the credit for the waste Stoddard solvent is ignored, then the payback period is shortened to 4.7 years. This time span also exceeds the assumed hurdle rate of 3 years. Therefore, modification will only be justified when the cost of the virgin solvent and/or the cost of disposal rises substantially from current levels.

4.8.3 Station #4 - Counter-Current Cleaning

By installing a spring loaded three-way valve, a check valve, and some additional piping, the task of transferring used solvent from the clean tank to the dirty tank can be made simpler and safer for the operator. A spring-loaded three-way valve is used so that the operator cannot leave the valve in the transfer position inadvertently. Material and labor costs are shown in Table 4-3. Annual savings would be $220 (credit

TABLE 4-2 ECONOMIC ANALYSIS FOR INCREASING THE DEGREE OF CLEANING EFFICIENCY AT STATION #1

INSTALLED COSTS	
Pump (Seal-less magnetic drive with 3/4 HP explosion proof motor), delivered cost	$1,100
Strainer, delivered cost	$ 650
Pressure Indicator, delivered cost.	$ 60
Piping (30 feet of 1" C.S., 3 ells, 4 tees, (2) 1" valves, (2) 1/2" valves).	$ 300
Installation including labor and supplies	$ 800
Total Installed Cost	$2,910
INCREMENTAL SAVINGS, YEARLY	
Raw Materials, Solvents (a)	$ 620
Disposal Costs (b)	- $ 260
Labor	negl.
Other (Electrical) (c)	negl.
Savings	$ 360
Payback Period, Years	8.1

(a) Based on reducing the need for virgin Stoddard solvent from 1,320 to 825 gallons per year @ $1.25/gal.

(b) Based on reducing the volume of spent solvent from 660 to 165 gallons per year. A credit of $0.52/gal is paid to the facility by an off-site recycler.

(c) Electrical costs would be very small since the system would only operate for a few minutes per part.

(d) Payback period equals total installed cost/savings. Depreciation, taxes, and fees were not included in the calculation of payback period.

TABLE 4-3 ECONOMIC ANALYSIS OF MODIFYING STATION #2 FOR A TWO-STEP COUNTER-CURRENT CLEANING OPERATION

INSTALLED COSTS	
Piping (20 feet of 1/2" C.S., 4 eels, 1 tee, (1) check valve, (1) spring loaded 3 way valve).	$ 300
Installation including labor and supplies	$ 300
Total Installed Costs	$ 600
INCREMENTAL SAVINGS, YEARLY	
Raw Materials, Solvents (a)	$ 380
Disposal Costs (b)	- $ 160
Labor	---
Other (Electrical) (c)	---
Savings	$ 220
Payback Period, Years	2.7

(a) Based on reducing the need for virgin Stoddard solvent from 900 to 600 gallons per year @ $1.25/gal.

(b) Based on reducing the volume of spent solvent from 600 to 300 gallons per year. A credit of $0.52/gal is paid to the facility by an off-site recycler.

(c) Payback period equals total installed cost/savings. Depreciation, taxes and fees were not included in the calculation of payback period.

for the used Stoddard) or $380 (no credit). Since these savings equate to payback periods of 2.7 and 1.6 years, this modification appears justified.

4.8.4 Station #6 - Level Alarm

To use the vapor degreaser as a recovery still, a low level alarm indicator must be installed. The indicator provides the operator with a warning since the recovery operation must be stopped before the steam heating coils are exposed. Modification of the vapor degreaser would require drilling a hole in the side of the unit and installing the indicator alarm. The hole would have to be located approximately an inch above the height of the heating coil. Blueprints of the vapor degreaser were reviewed and installation of the level alarm does not appear to be a problem.

The cost of purchasing and installing the level alarm is shown in Table 4-4. This alarm would allow the operators to recover 246 gallons of solvent from the sludge each year. Based on a raw material cost of $4.00 per gallon, the payback period is slightly more than 7 months. Disposal costs have been excluded from the analysis since they are unknown.

4.8.5 Station #7 - Sludge Removal

By installing a pump and filter unit on the epoxy-based paint stripping tank, the amount of sludge requiring disposal can be reduced. Paint that is allowed to remain inside the tank slowly dissolves over a period of time and hence decreases the stripping efficiency of the solvent. When disposal is required, much of the solvent is lost in the sludge. The current operating procedure is to remove the sludge once every 3 to 4 years. This analysis is based on a continuous purging of the tank, so as to increase the lifetime of the entire bath.

Facility personnel estimated that each paint stripping tank in the facility generates 720 gallons of sludge per year (this sludge remains inside the tank until solution replacement is required). Assuming that this sludge contains 20 volume percent dry paint, the sludge contains 576 gallons of stripper solution and 144 gallons of paint. If the sludge contained 40 percent dry paint by volume (assumed for continuous removal of the sludge), then only 216 gallons of stripper solution would be lost each year. Based on a raw material cost of $6.00 per gallon for stripping solution and a disposal

TABLE 4-4 ECONOMIC ANALYSIS OF MODIFYING STATION #6 TO ALLOW FOR RECOVERY OF SOLVENT

INSTALLED COSTS	
Level Control (Sensall 501), delivered cost	$ 150
Alarm, delivered cost.	$ 50
Installation including labor and supplies	$ 400
Total Installed Costs	$ 600
INCREMENTAL SAVINGS, YEARLY	
Raw Materials, Solvents (a)	$ 980
Disposal Costs (b)	---
Labor	negl.
Other (Electrical) (c)	negl.
Savings	$ 980
Payback Period, Years	0.6

(a) Based on saving 246 gallons per year of solvent @ $4.00 per gallon. Recovery would occur until the level of oil contamination in the bottoms reached 60 to 70 percent.

(b) Current disposal costs for spent solvent from the vapor degreaser are unknown. Inclusion based on an assumed cost of $3.00/gal. would result in a savings of $740 or an overall payback period of 0.3 years.

(c) Payback period equals total installed cost/savings. Depreciation, taxes and fees were not included in the calculation of payback period.

TABLE 4-5 ECONOMIC ANALYSIS OF MODIFYING STATION #7 FOR CONTINUOUS REMOVAL OF PAINT SLUDGE

INSTALLED COSTS	
Filter (316 SS dual basket unit), delivered cost.	$4,000
Pump (Seal-less magnetic drive, 25 gpm, 316 SS), delivered cost.	$1,100
Pressure Indicator (2)	$ 120
Piping (50 feet of 1-1/2 C.S., 6 ells, 3 tees, 3 valves).	$ 400
Installation including labor and supplies	$1,200
Total Installed Costs	$6,820
INCREMENTAL SAVINGS, YEARLY	
Raw Materials, Solvents (a)	$2,160
Disposal Costs (b)	$1,080
Labor (c)	- $ 470
Other (electricity, filter bags, etc.) (d)	$ 500
Savings	$2,270
Payback Period, Years	3.0

(a) Based on saving 360 gallons per year of virgin stripper @ $6.00/gal.

(b) Based on reducing the volume of waste generated by 360 gallons per year @ $3.00/gal. assumed disposal cost.

(c) Based on 1 hour per week labor @ $9.00/hr.

(d) Based on replacing the two filter bags every 3 weeks @ $12.00/bag. The remaining annual costs are for power and miscellaneous.

(e) Payback period equals total installed cost/savings. Depreciation, taxes and fees were not included in the calculation of payback period.

cost of $3.00 per gallon ($165 per drum), the net annual savings amount to $2,270. This estimate includes $470 per year for labor and $500 per year for miscellaneous expenses. The cost of purchasing and installing a pump and filter unit is estimated to be $6,820. The payback period for this option was calculated as being 3.0 years.

4.9 Summary and Discussion

Ten stations were selected for the initial audit. After conducting the initial audit, the number of stations at which detailed study was performed was reduced to four. These four stations (Station #1 - Cold Cleaning Tank, Station #4 - Ball Bearing Cleaning, Station #6 - Vapor Degreasing, and Station #7 - Epoxy Paint Stripping) represent the major types of solvent using operations at the facility. After selecting the four representative stations, waste minimization options were formulated for each operation. These options were then tabulated and rated for waste reduction effectiveness, extent of current use, and future application potential. From these ratings, several options were selected for additional economic analysis. The results of this analysis are shown in the table below.

TABLE 4-6. SUMMARY OF SOURCE CONTROL OPTIONS INVESTIGATED

Station	Control Method	Waste Reduction (%)(c)	Waste Reduction (gal/yr)	Capital Cost	Savings	Payback
1	Closed Tank(d)	-	-	-	-	-
1	Increased Agitation	75(37)	495	$2,910	$360 $620 (a)	8.1 Years 4.7 Years
4	Counter-Current Cleaning	50(33)	300	$ 600	$220 $380 (a)	2.7 Years 1.6 Years
6	Level Alarm	62(40-50)	246	$ 600	$980 (b)	7 Months
7	Sludge Removal	50(64)	364	$6,820	$2,770	3.0 Years

(a) Assumes no credit for the waste solvent.
(b) Excludes savings due to reduced disposal costs.
(c) Quantity in parentheses represents percent reduction in virgin solvent use.
(d) Modification of the existing tank would not be viable.

For Station #1, 7 options were discussed and 2 were selected for additional economic analysis. The first option, use of a closed tank, was determined to be economically prohibitive. The second option, increased agitation, was also proven uneconomical because of a payback period ranging from 4.7 to 8.0 years (with/without credit for the used solvent).

For Station #4, 8 options were discussed and 1 was selected for additional economic analysis. The option, use of a counter-current cleaning sequence, exhibited a payback period ranging from 1.6 to 2.7 years (with/without credit for the used solvent). Since this range is less than the maximum hurdle rate of 3 years, this option is recommended for implementation.

For Station #6, 14 options were discussed and 1 option was selected for additional economic analysis. The option, installation of a level alarm so that the vapor degreaser can be used as a recovery still, had a payback period of 7 months. This option would therefore be recommended for implementation.

For Station #7, 7 options were discussed and 1 option was selected for additional economic analysis. The option, continuous filtering of the stripper bath, had a payback period of 3.0 years. Since this is the same time frame as the maximum hurdle rate (3 years) this option would be recommended for additional investigation.

5. AUDIT REPORT FOR FACILITY S-2

5.1 Facility Description

Facility S-2, located in Southern California, is a major manufacturer of multilayer ceramic capacitors used primarily by the telecommunications and military electronics industries. Production operations are performed in two separate buildings located within close proximity to each other. Ceramic materials are formulated in the Annex Building and then transferred to the Main Facility where the capacitors are formed. Various finishing operations are performed at both buildings.

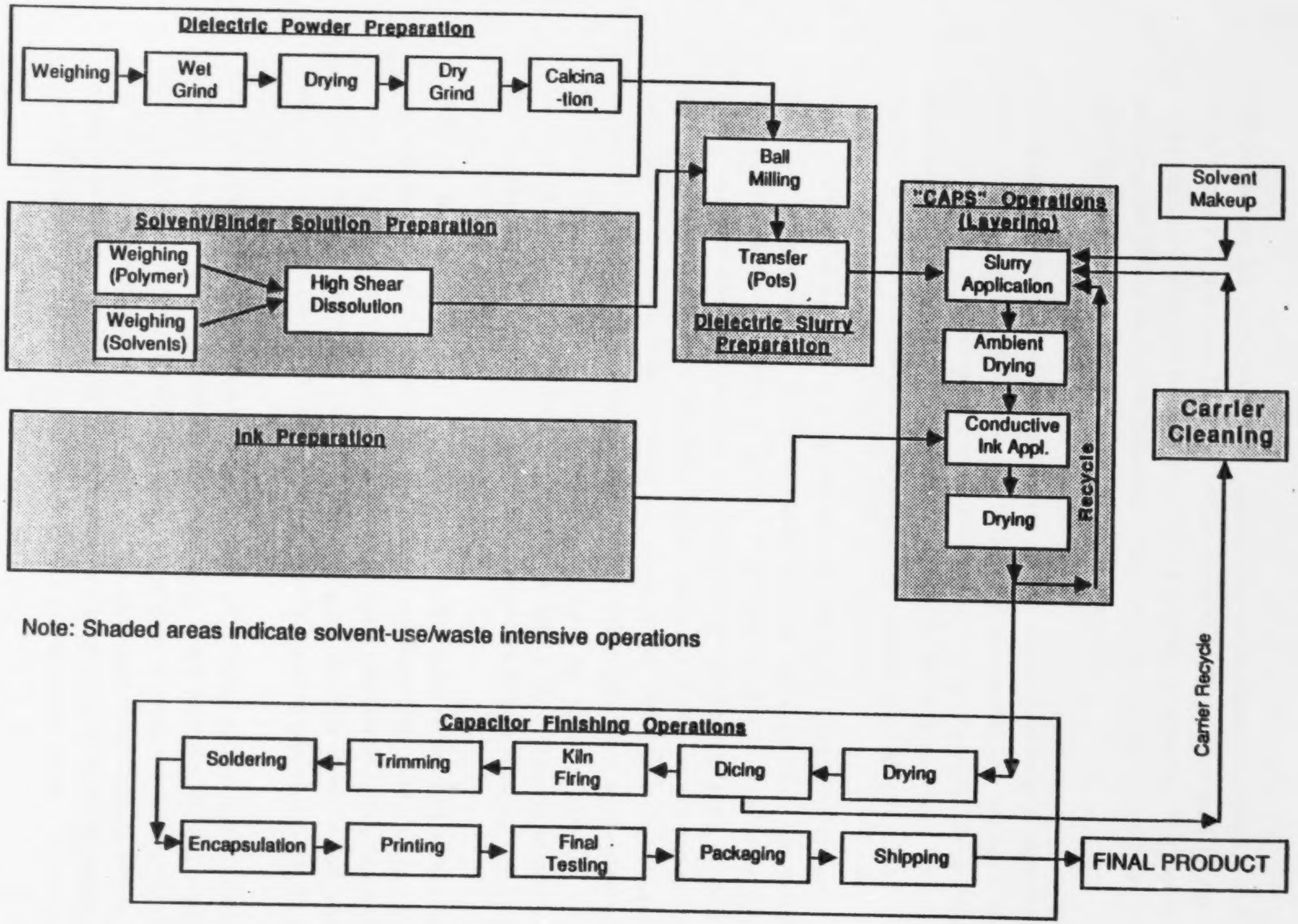
5.2 Equipment Layout Description

Major operations depicted schematically in the block flow diagram (Figure 5-1), include: formulation of the ceramic or dielectric material; mixing of the material with a solution of polymer in solvent to form a slurry; sequential application of the slurry and a metallic ink onto a carrier; dicing and kiln firing of the capacitors; soldering of metal caps to the capacitor; and encapsulation. Due to the proprietary nature of these operations, no information regarding physical equipment layout is available.

5.3 Process Description

The process begins with the preparation of dielectric powder which involves such operations as weighing, dry and wet grinding, drying, and calcination. The input materials may include barium titanate and various metal oxides. The semiproduct is a finely divided dielectric ceramic powder with predetermined phase composition, particle size, and other desired properties. All of these operations are performed in the Annex Building.

At the capacitor slurry preparation area, the ceramic powder is placed inside a ball mill. Next, RM-513 (a proprietary non-chlorinated solvent mixture) and a polymeric binder are weighed out, mixed together until the polymer dissolves, reweighed, and then thoroughly mixed with the powder in the ball mill. After milling, the slurry is transferred into stainless steel pots. The pots are fitted with a cover and air driven mixer unit and sent to storage for later use.


Dielectric Powder Preparation
Weighing
Wet Grind
Drying
Dry Grind
Calcina -tion
Solvent/Binder Solution Preparation
Weighing (Polymer)
Weighing (Solvents)
High Shear Dissolution
Ink Preparation
Ball Milling
Transfer (Pots)
Dielectric Slurry Preparation
"CAPS" Operations (Layering)
Slurry Application
Ambient Drying
Conductive Ink Appl.
Drying
Recycle
Solvent Makeup
Carrier Cleaning
Carrier Recycle
Capacitor Finishing Operations
Soldering
Trimming
Kiln Firing
Dicing
Drying
Encapsulation
Printing
Final Testing
Packaging
Shipping
FINAL PRODUCT

Note: Shaded areas indicate solvent-use/waste intensive operations

Figure 5-1. Block Flow Diagram for Ceramic Capacitor "CAPS" Manufacturing Process.

The capacitors are produced at the Capacitor Advanced Production System or "CAPS" room located in the Main Facility. After transferring the slurry pots to the CAPS room, the slurry is poured into one of six slurry application systems. The transfer pots are returned to the Annex for cleaning. The slurry application systems are used to apply successive layers of the ceramic slurry to a carrier.

The slurry is pumped from the application system feed pot, through a dual-cartridge filter system, and into the application unit. The application unit applies a uniform layer of ceramic material to the carrier as it passes through the unit. Since the slurry is continuously recirculated through the system, RM-513 is occasionally added to the feed pot to correct for changes in viscosity due to solvent evaporation.

Production begins by sending a carrier through the slurry application system. After the coating has dried, the carrier is passed through the conductive ink application system where a metallic layer is applied. Application of this metallic layer occurs in such a way that when the material is cut into cubes, alternating layers of metal are exposed at opposite ends of the cube (metal layers 1,3,5, etc. on one end and layers 2,4,6, etc. on the opposite end). After application of the metallic layer, the carrier is inspected, passed through a drying unit, and returned to the slurry application system for deposition of another layer. If defects are found during inspection, the off-spec material is removed from the carrier, and since such defects indicate problems with the ink application system, this system is cleaned before further production is run.

After the desired number of layers have been applied to the carrier (the actual number required depends on the desired capacitance of the capacitors being produced), the material is cut into small cubes and removed from the carrier. This operation is known as dicing. From this step, the capacitors are returned to the Annex and the carriers are sent to the CAPS room cleaning area for cleaning and subsequent reuse.

At the Annex, the capacitors are heated to drive off residual solvent and then fired in a kiln. Next, they are sent to the trimming area where abrasive blasting is used to trim their size to the proper tolerance. This step is followed by the soldering operation where metal caps are attached to the capacitor along opposite edges. The metal caps form an electrical connection with the alternating metallic layers, and provide a means for connecting the capacitor into an electrical circuit.

If the capacitors are to be sold in "chip" form, they are sent to testing and final inspection. If they are to be sold in "conformal coated" form, wire leads are attached to the metal caps, the capacitors are coated with encapsulating material, and identification markings are printed on the coating. After printing, these capacitors are also sent to testing and final inspection.

5.4 Waste Stream Description

The major solvent wastes associated with the production of ceramic capacitors include:

- Ball mill off-specification slurry;
- Ball mill cleaning waste;
- Transfer pot residual slurry;
- Transfer pot cleaning waste;
- Slurry application system off-spec slurry waste;
- Slurry application system feed pot cleaning waste;
- Slurry application system flush;
- Slurry application system filter cartridges;
- Slurry application system carrier cleaning;
- General equipment cleaning waste; and
- TCA primary recovery bottoms.

The most common solvents used for cleaning include 1,1,1-Trichloroethane (TCA), RM-513, and isopropyl alcohol (IPA). Major solvent waste streams and their generation rates are shown in Table 5-1. The following sections discuss each current waste generating operation in detail.

5.4.1 Ball Mill Off-Spec Slurry and Cleaning Waste

Ball mills are cleaned whenever a batch of slurry becomes contaminated, or whenever it is required to change the type of slurry being milled in the unit (the facility tries to maximize dedication of equipment to a particular type). The first cleaning step (see Figure 5-2A), is to empty the off-spec slurry into a 55-gallon drum. Next, recycled TCA is added to the mill and the mill rotated. After a given period of time, the TCA is emptied from the mill and added to the contents of the 55-gallon drum. Final

TABLE 5-1 SUMMARY OF MAJOR SOLVENT WASTE STREAMS

Waste Source/ Streams	Gallons/Week					Waste Management Method(a)
	Solids	RM-513	TCA	IPA	Total	
BALL MILL						
Off-Spec Slurry	1.2	18.8	---	---	20.0	S/L
Solvent Cleaning	0.3	9.7	20.0	---	30.0	S/L
TRANSFER POTS						
Primary Cleaning (b)	---	---	---	---		---
Secondary Cleaning	1.2	---	230.3	---	231.5	D(on)
SLURRY APPLICATION						
Off-Spec Slurry (c)	---	---	---	---	---	---
Feed Pot Cleaning (b)	---	---	---	---	---	---
System Flush	0.1	14.9	---	---	15.0	I
Filter Cartridges	11.1	2.2	---	---	11.1	S/L
Carrier Cleaning	0.6	---	110.4	---	111.0	D(on)
GENERAL CLEANING						
Chlorinated	2.9	---	579.6	---	582.5	D(on)
Non-Chlorinated	0.4	---	---	93.6	94.0	I
TCA PRIMARY RECOVERY						
Still Bottoms	4.7	---	50.3	---	55.0	D(off)
WASTE RECYCLED						
On-Site (d)	---	---	870.0	---	870.0	
Off-Site (e)	---	---	32.7	---	32.7	
Total (d,e)	---	---	902.7	---	902.7	
WASTE DISPOSED						
Incinerated	0.5	14.9	---	93.6	109.0	
Solidified/Land (f)	17.3	30.7	37.6	---	85.6	
Total	17.8	45.6	37.6	93.6	194.6	

(a) D = distilled on- or off-site, I = incinerated off-site, S = solidified on-site, and L = landfilled off-site.

(b) Waste included in the Ball Mill solvent cleaning waste.

(c) Waste included in the Ball Mill off-spec slurry waste.

(d) Excludes still bottoms that are sent off-site for recovery.

(e) Excludes bottoms from secondary recovery (solvent recovery assumed to be 65 percent).

(f) Includes waste excluded in (d) and (e).

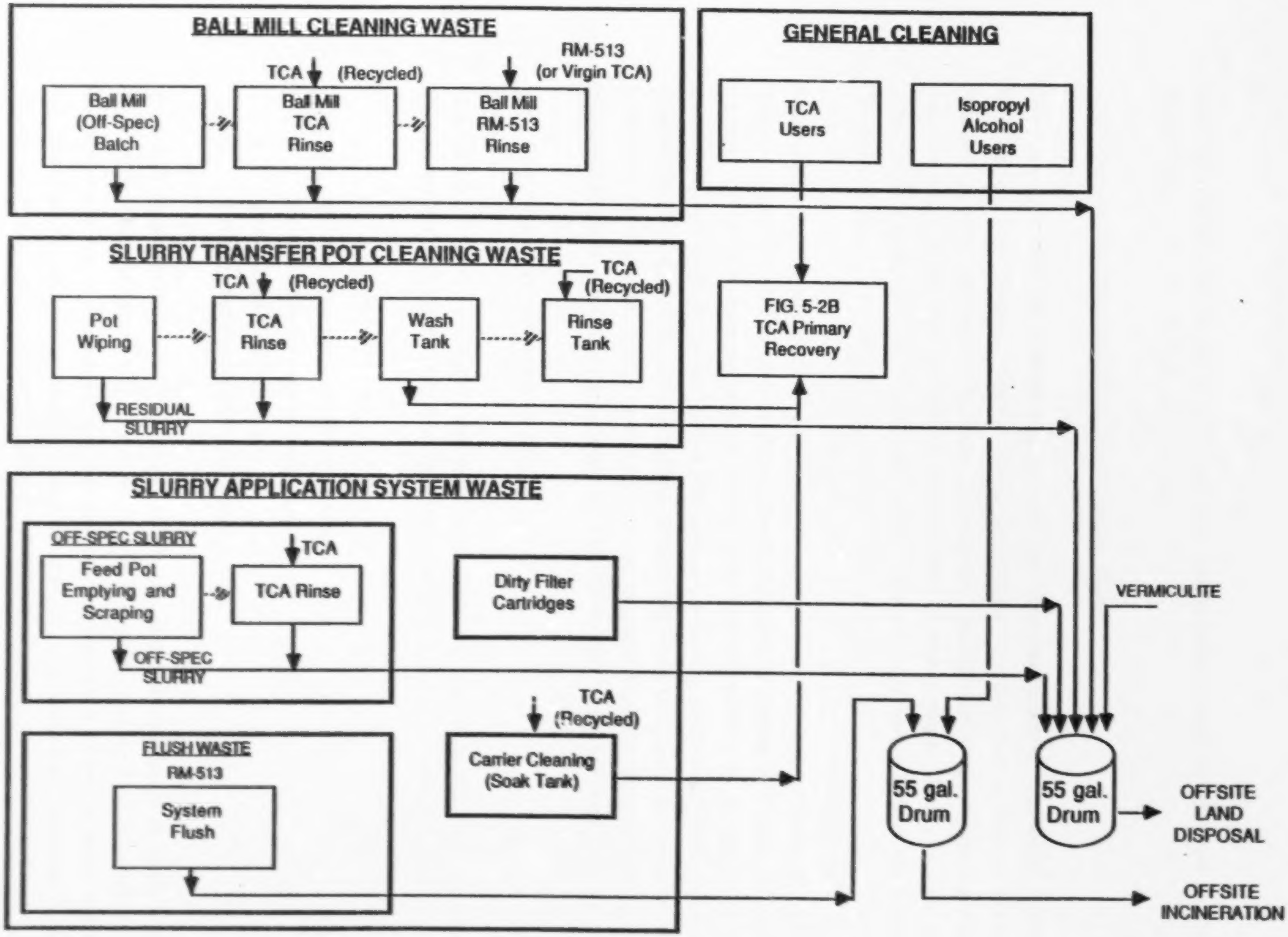

BALL MILL CLEANING WASTE
TCA
(Recycled)
RM-513
(or Virgin TCA)
Ball Mill
(Off-Spec)
Batch
Ball Mill
TCA
Rinse
Ball Mill
RM-513
Rinse
GENERAL CLEANING
TCA
Users
Isopropyl
Alcohol
Users
SLURRY TRANSFER POT CLEANING WASTE
TCA
(Recycled)
TCA
(Recycled)
Pot
Wiping
TCA
Rinse
Wash
Tank
Rinse
Tank
RESIDUAL
SLURRY
FIG. 5-2B
TCA Primary
Recovery
SLURRY APPLICATION SYSTEM WASTE
OFF-SPEC SLURRY
TCA
Feed Pot
Emptying and
Scraping
TCA Rinse
OFF-SPEC
SLURRY
Dirty Filter
Cartridges
VERMICULITE
TCA
(Recycled)
FLUSH WASTE
RM-513
System
Flush
Carrier Cleaning
(Soak Tank)
55 gal.
Drum
55 gal.
Drum
OFFSITE
LAND
DISPOSAL
OFFSITE
INCINERATION

Figure 5-2A. Current Solvent Waste Generation.

washing with RM-513 is then performed, with the resulting waste being added to the same drum.

5.4.2 Transfer Pot Residual Slurry and Cleaning Waste

Dirty transfer pots are cleaned in a primary and secondary cleaning operation at the formulation area cleaning room. These operations are depicted in Figure 5-2A. Primary cleaning consists of manually scraping the residual slurry out of the pot and into the same drum used for storing the ball mill cleaning waste. Next, the pot is rinsed with a small amount of recycled TCA. This waste is also added to the same 55-gallon drum.

Secondary cleaning employs a two-step wash/rinse sequence in unheated tanks of TCA. Washing is performed in a tank of dirty solvent, followed by rinsing in a tank of clean solvent. When the cleaning ability of the dirty solvent lessens to an appreciable degree, the dirty solvent is sent to the TCA primary recovery system and fresh solvent is added to the tank. This tank is then designated the rinse tank and the former rinse tank becomes the wash tank. Facility personnel estimate that the dirty transfer pot cleaning operation (secondary only) generates 230 gallons of waste per week.

5.4.3 Slurry Application System Waste

Five different types of waste are associated with the slurry application systems located in the CAPS room. The five waste streams are:

- Off-spec slurry;
- Solvent used for feed pot cleaning;
- Solvent used for system flushing;
- Spent filter cartridges; and
- Solvent used for cleaning carriers.

When it is apparent that a batch of slurry is off-spec (the material tends to crack and flake off the coated carrier), it is drained back into the feed pot which is taken to the CAPS cleaning room. There, the off-spec slurry is poured into a 55-gallon drum while the operator manually scrapes the inside of the pot. Rinsing with recycled TCA follows, with this waste also being added to the 55-gallon drum.

Flushing of the system must then be performed to remove the off-spec slurry that remains inside. In addition to the cleaning associated with off-spec batches, the systems are routinely flushed out once per week to prevent the buildup of solidified material inside the system, or whenever the formulation used in a machine is changed (each system is dedicated to a particular formulation for as long as possible). Cleaning is performed by pouring 2 to 3 gallons of RM-513 into the clean supply pot. The solvent is then circulated through the system for several hours. It is estimated tha the facility generates 15 gallons of flush waste per week.

Following a flush, the two filter units on each system are also changed. Each filter unit contains two disposable filter cartridges. The filter system is arranged so that one filter is in use while the other serves as a spare. When one filter plugs, the plugged filter is valved out and the other one is valved in. Changing of the filters generates 36 spent cartridges per week for all systems combined.

Cleaning of the carriers used to form the capacitors is performed at the cleaning area adjacent to the CAPS room. Dried slurry is removed from the carriers using recycled TCA in a soak tank. The waste from this operation, estimated to be 111 gallons per week, is stored in specially designated 55-gallon drums. When full, the drums are taken to the TCA primary recovery system located in the Annex Building.

5.4.4 General Cleaning Wastes

The two major types of solvent used in the facility for general cleaning are TCA and isopropyl alcohol. Facility personnel estimate that 582 gallons per week of dirty TCA from general cleaning operations are processed in the primary recovery system. General cleaning also accounts for the generation of 94 gallons per week of dirty isopropyl alcohol. This waste is placed in specially marked 55-gallon drums and disposed as flammable wastes.

5.4.5 TCA Primary Recovery Waste

Recycling begins when TCA is added to the 55-gallon feed drum either by way of dedicated piping (Annex Building), or by emptying a storage drum into the feed drum (see Figure 5-2B for a block flow diagram of the system). The feed drum is equipped with a float-controlled pump that transfers the solvent into the dirty solvent tank.

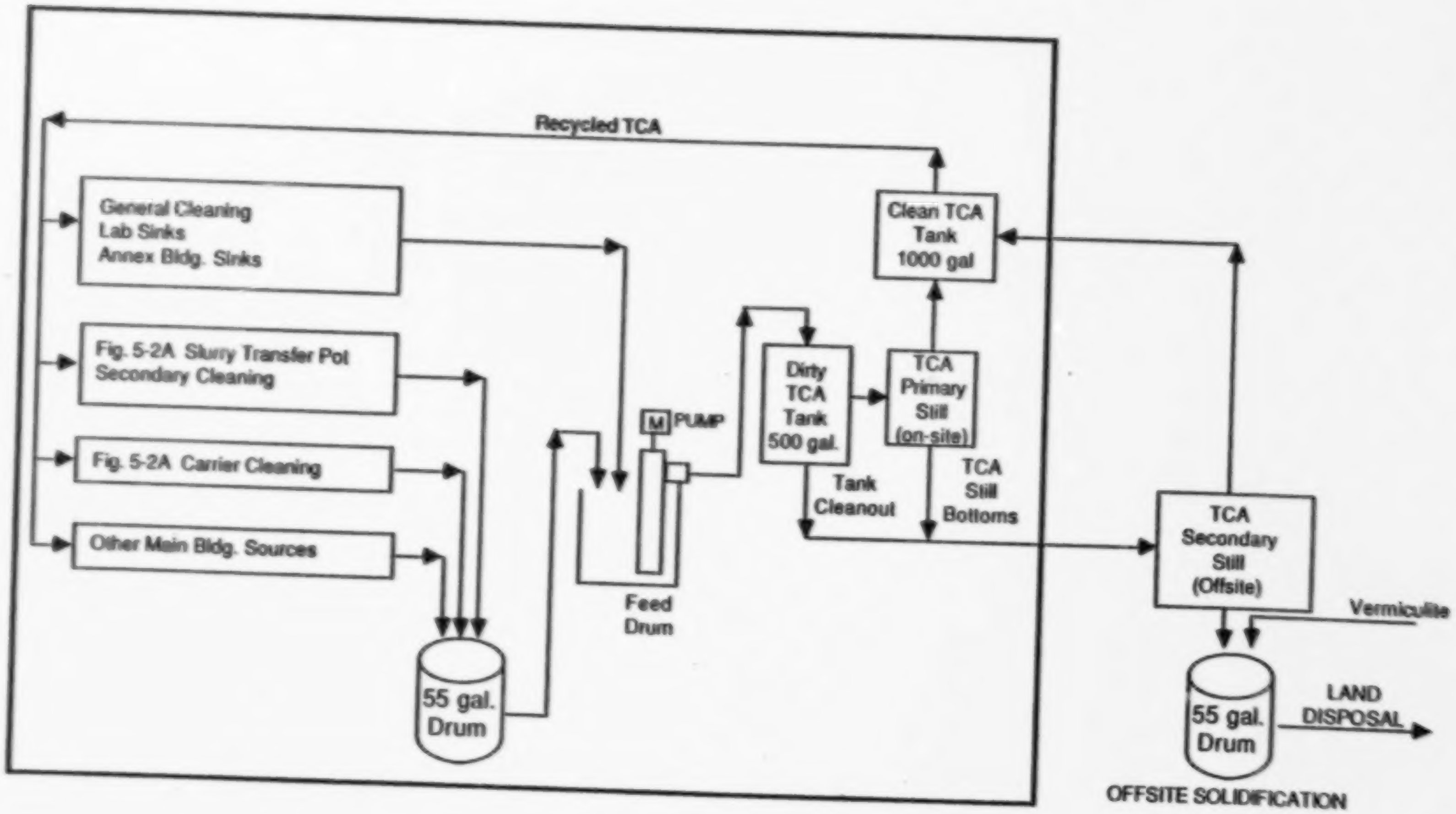

Recycled TCA
General Cleaning
Lab Sinks
Annex Bldg. Sinks
Fig. 5-2A Slurry Transfer Pot
Secondary Cleaning
Fig. 5-2A Carrier Cleaning
Other Main Bldg. Sources
55 gal.
Drum
M
PUMP
Feed
Drum
Dirty
TCA
Tank
500 gal.
TCA
Primary
Still
(on-site)
Clean TCA
Tank
1000 gal
Tank
Cleanout
TCA
Still
Bottoms
TCA
Secondary
Still
(Offsite)
Vermiculite
55 gal.
Drum
LAND
DISPOSAL
OFFSITE SOLIDIFICATION

Figure 5-2B. Current TCA Recycle and Waste Generation.

From this tank, the solvent is pumped into the still. The still holds 100 gallons per batch and processes two batches per day. Recovery efficiency for the still is estimated to be 95 percent. Overhead from the still is condensed and collected in the clean solvent tank. Clean solvent may then be pumped to the dedicated solvent supply lines (Annex Building), to a 55-gallon drum loading system, to the dirty tank for reprocessing, or back to the still for clean-out.

Still bottoms are removed from the unit about once per week by allowing the still to drain into a 55-gallon drum. This waste contains 60 to 70 percent solvent and 30 to 40 percent solids by weight. Following removal of the bottoms, the still is then rinsed out with recycled solvent from the fresh solvent tank. This rinse is returned to the dirty solvent tank for reprocessing. The 55 gallons of still bottoms removed from the still are then sent off-site for additional recovery of TCA.

5.5 Current Waste Management Profile

The major waste management methods used by the facility are summarized in Table 5-1 and include: on-site solidification followed by off-site landfilling; on-site distillation followed by off-site distillation, solidification, and landfilling; and off-site incineration. The methods used depend primarily on the nature of the wastes generated (i.e., degree of cross contamination with other solvents and percent solids). Most TCA is distilled on-site (unless contaminated heavily with solids or RM-513) and most isopropyl alcohol is mixed with other flammable wastes and incinerated off-site. The following paragraphs discuss the waste management methods used for each waste stream.

All of the waste due to off-spec slurry, ball mill cleaning, primary transfer pot cleaning, and feed pot cleaning, are mixed together and solidified with vermiculite on-site (see Figure 5-2A). Also mixed in with this waste are the used filter cartridges from the slurry application systems. Facility personnel estimate that a total of 50 gallons per week of solvent waste (excluding cartridges) must be solidified. Based on an initial volume of 50 gallons or one drum, the solidification process increases the volume of waste to three drums. It currently costs $68 per drum ($1.25 per gallon) of solidified waste to have it hauled away and landfilled.

For the primary recovery of spent TCA, the facility operates an on-site distillation unit. Operations responsible for generating this waste include secondary cleaning of transfer pots, cleaning of carriers, and general facility cleaning. Mixtures of TCA and RM-513 (or other solvents) are not processed in the unit. Facility personnel estimate that the unit processes 925 gallons of TCA and generates 55 gallons of still bottoms per week.

The still bottoms are sent to an off-site facility for additional recovery of TCA. Residues from this operation are solidified and then land disposed. Facility S-2 receives 33 gallons of TCA per week from the off-site recovery facility for a charge of $3.54 per gallon. Additional costs include $1.25 per gallon of solidified sludge for the solidification and landfilling of the still bottoms residue.

Flammable wastes that do not contain chlorinated solvents, such as RM-153 used for slurry application system flushing or isopropyl alcohol used for general cleaning, are mixed together and shipped off-site for incineration. It currently costs the facility $3.23 per gallon for this service (this price includes the cost of the drum). If the waste is contaminated with chlorinated solvents, then the waste must be solidified and landfilled.

5.6 Postulated Waste Minimization Options

The major solvent waste generating operations audited at the facility include: cleaning of ball mills, slurry transfer pots, and slurry application systems; general cleaning; and on-site recovery of dirty TCA. Waste minimization options, both existing and proposed, are discussed in the following sections.

5.6.1 Ball Mill Off-Spec Slurry and Cleaning Waste

As shown in Table 5-1, off-spec slurry accounts for 20 gallons per week of waste, while solvent cleaning of the ball mills generates 30 gallons per week. Included in these rates are the wastes due to primary cleaning of the transfer pots, off-spec slurry from slurry application, and slurry application system feed pot cleaning. Since none of this waste can be sent off-site for incineration (the slurry has too high a solids content and the cleaning waste contains chlorinated solvent), all of these wastes are currently mixed together and solidified for off-site landfilling. Control options currently in full or partial use include:

- Dedicate ball mills to slurry formula.

By dedicating each ball mill to the production of one particular slurry formulation, the need for cleaning between batches is reduced. It was reported that this practice is in wide use.

- Increase degree of quality control.

Monitoring the quality of the feed materials before use decreases the likelihood of producing a contaminated or off-specification batch of slurry. Other important items include instructing employees in the proper ways of handling materials so as to minimize product contamination. The facility has recently implemented a program aimed at reducing the causes of off-spec slurry production.

In addition to product contamination, another major cause of off-specification material is due to inaccuracies in weighing operations. For critical materials such as dielectric ceramics, there should be a double check on the weighing off operation (one operator should check the other). In particular, incoming materials must be checked and the nominal weight not accepted as valid. It is not uncommon for bags and drums to be off by as much as 2 to 10 percent by weight on the high side. This error occurs because a suppliers weighing machines are normally set to give a high error so that the customer is assured of receiving at least the amount marked on the package.

- Use two-step mill flush.

This method relies on the use of two small batches of solvent for cleaning as opposed to one large batch. The method begins by pouring a small amount of solvent into the mill and allowing the mill to rotate. After a given period of time, the dirty solvent is removed from the mill and the procedure is repeated with a fresh batch of solvent. This method is currently in full use.

To achieve an even greater reduction in the amount of cleaning solvent used, a two-step counter-current cleaning sequence may be employed. This method requires that the second batch of waste solvent produced (the rinse), be used as the first batch of solvent (the wash) for the next mill cleaning. It is recommended that the use of this method be fully investigated.

New options considered for minimizing the wastes associated with ball mill cleaning are depicted in Figure 5-3A. These options include:

- Segregate and recycle RM-513 wastes.

By keeping the off-spec slurry wastes segregated from the waste that contains TCA (primary ball mill, transfer pot, and feed pot rinse), a recyclable waste stream is produced. RM-513 can be reclaimed from the off-spec slurry by installing a small recovery system designed for this service.

- Standardize solvents used and recycle.

By using RM-513 in place of TCA for cleaning of the ball mills and primary rinsing of the dirty transfer and feed pots, a waste stream much more amenable to recycling is generated. This is due to the elimination of chlorinated solvent from the waste and the improvement in the economics of recycling due to the larger volume of RM-513 involved. Even if recycling of the RM-513 is not desired by the facility, standardization will make the waste more amenable to off-site incineration since no halogens will be present in the waste.

5.6.2 Transfer Pot Residual Slurry and Cleaning Waste

The primary cleaning of slurry transfer pots generates a waste that is added in with the ball mill and feed pot cleaning wastes. Secondary cleaning of transfer pots generates 231 gallons per week of dirty TCA. This waste is reclaimed on-site and the solvent is returned to the cleaning operation. Solvent loss by way of the still bottoms is addressed in the section on TCA primary recovery wastes. Control options currently in full or partial use include:

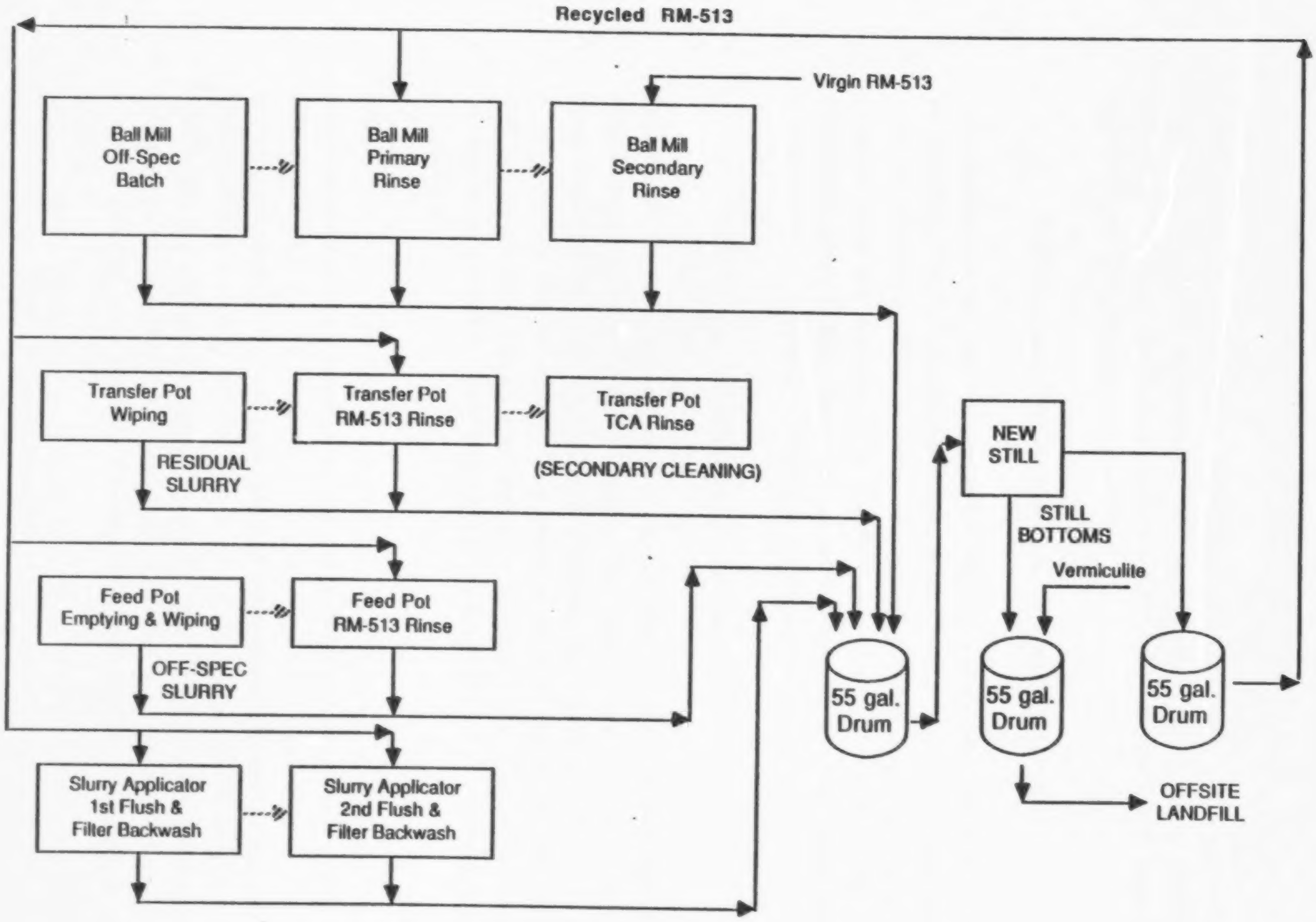

Recycled RM-513
Virgin RM-513
Ball Mill Off-Spec Batch
Ball Mill Primary Rinse
Ball Mill Secondary Rinse
Transfer Pot Wiping
RESIDUAL SLURRY
Transfer Pot RM-513 Rinse
Transfer Pot TCA Rinse
(SECONDARY CLEANING)
Feed Pot Emptying & Wiping
OFF-SPEC SLURRY
Feed Pot RM-513 Rinse
Slurry Applicator 1st Flush & Filter Backwash
Slurry Applicator 2nd Flush & Filter Backwash
55 gal. Drum
NEW STILL
STILL BOTTOMS
Vermiculite
55 gal. Drum
55 gal. Drum
OFFSITE LANDFILL

Figure 5-3A. Proposed RM-513 Cleaning Solvent Recycle System.

- Wipe transfer pots prior to solvent cleaning.

Cleaning transfer pots by wiping or scraping out the contents of the pot reduces the amount of cleaning solvent required. If enough waste material can be removed from the pot before using solvent, then a simple solvent rinse may adequately clean the pot. This procedure is in full use at the facility.

- Reduce evaporative loss of solvent from cleaning tanks.

Air emissions are the leading cause of uncontrolled solvent loss. While the control of air emissions does not reduce the amount of solid waste produced, it does reduce the need for purchasing virgin solvent. To reduce air emissions, the two secondary cleaning tanks are equipped with hinged type covers. The facility has recently instituted a policy to fully instruct personnel in the proper ways to operate equipment so that wastes and evaporative losses are minimized.

- Increase cleaning efficiency of cold cleaning tanks.

The amount of solvent waste due to replacement of tank contents can often be reduced by increasing cleaning efficiency. One viable method is to use a pump and jet spray unit inside the tanks. The jet spray increases the turbulence, which then leads to a more vigorous cleaning action. Care should be taken to ensure that the lids on each tank are closed while the jet spray unit is in operation, since its use can lead to an increase in air emissions. Both cleaning tanks are equipped with a pump and jet spray arrangement.

Another commonly used way to increase cleaning efficiency is to employ a two-step counter-current cleaning operation (a wash-rinse sequence). Parts are initially washed in a tank of dirty solvent, followed by rinsing in a tank of clean solvent. The tank of dirty solvent removes the bulk contamination and reduces the load on the clean tank. This method is currently utilized at the facility by operating one tank as the dirty (wash) tank and the other as the clean (rinse) tank. When the dirty solvent requires replacement, it is removed from the wash tank and the tank is refilled with clean solvent. This tank then becomes the rinse tank and the old rinse tank is used for washing.

As a final note, cleaning efficiency can be readily increased by replacing the cold tanks with a vapor degreaser. Use of a vapor degreaser would provide excellent cleaning of the pots and also would reduce solvent use. Vapor degreasers use less solvent since they can often operate at contamination levels reaching 25 percent, as compared to cold cleaning operation which only reach 10 percent. However, since the facility currently recycles solvent from the cold cleaning tanks, their replacement would probably not be economically justifiable.

- o Segregate, standardize, and recycle cleaning wastes.

This recommended option has been discussed in Section 5.6.1 and is depicted in Figure 5-3A.

5.6.3 Slurry Application System Wastes

Flushing out of the slurry application systems generates approximately 15 gallons of RM-513 waste and 36 spent filter cartridges per week. These cartridges contain RM-513 waste and must be solidified along with the other wastes shown in Figure 5-2A. Cleaning of the carriers generates 111 gallons per week of dirty TCA. This waste is sent to the TCA primary recovery system. Control options currently in full or partial use (and discussed previously in Sections 5.6.1 and 5.6.2) include:

- o Increase degree of quality control.
- o Wipe feed pots prior to solvent cleaning.
- o Reduce evaporative loss of solvent from cleaning tanks.
- o Increase solvent cleaning efficiency.

Control options recommended for use include:

- o Use two-step slurry application system flush sequence.

By using a wash/rinse cleaning sequence with 1 to 2 gallons of solvent for each flush and by using the batch of rinse solvent from the previous system flush as the first wash batch, the amount of solvent waste generated can be cut in half.

- Segregate, standardize, and recycle pot cleaning waste.

This recommended option has been discussed in Section 5.6.1 and is depicted in Figure 5-3A.

- Segregate and recycle solvent flushing waste.

This recommended option has been discussed in Section 5.6.1 and is depicted in Figure 5-3A.

- Convert from cartridge filters to bag/metal mesh type.

The benefits of using bag filters in place of cartridge filters are that the loading capacities of bag filters can be as much as 4 to 5 times greater than equivalent cartridge units, and that spent bag filters occupy a minimum of space when disposed. The benefits of using metal mesh type filters are that these units are washable and do not contribute to the volume of waste generated. Since the facility currently performs system flushing with the filters in place, the potential exists for modifying the system to allow for back-washing of the metal mesh type filters. This would provide a means of cleaning the filters without generating a new waste stream.

5.6.4 General Cleaning Wastes

Isopropyl alcohol and TCA are the two main solvents used throughout the facility for general cleaning. The facility generates 582 gallons per week of TCA and 94 gallons per week of IPA. Dirty TCA is sent to the on-site TCA primary recovery system for reclamation, while the spent IPA is mixed with other flammable wastes and sent off-site for incineration. A control option recommended for use is:

- Segregate and recycle general cleaning wastes.

Isopropyl alcohol wastes can be readily recycled, provided they are not unduly contaminated with other cleaning solvents. Proper segregation of this waste from the other flammable wastes generated at the facility is essential for the success of this option. TCA is currently kept segregated from the other wastes and is recycled in the on-site still.

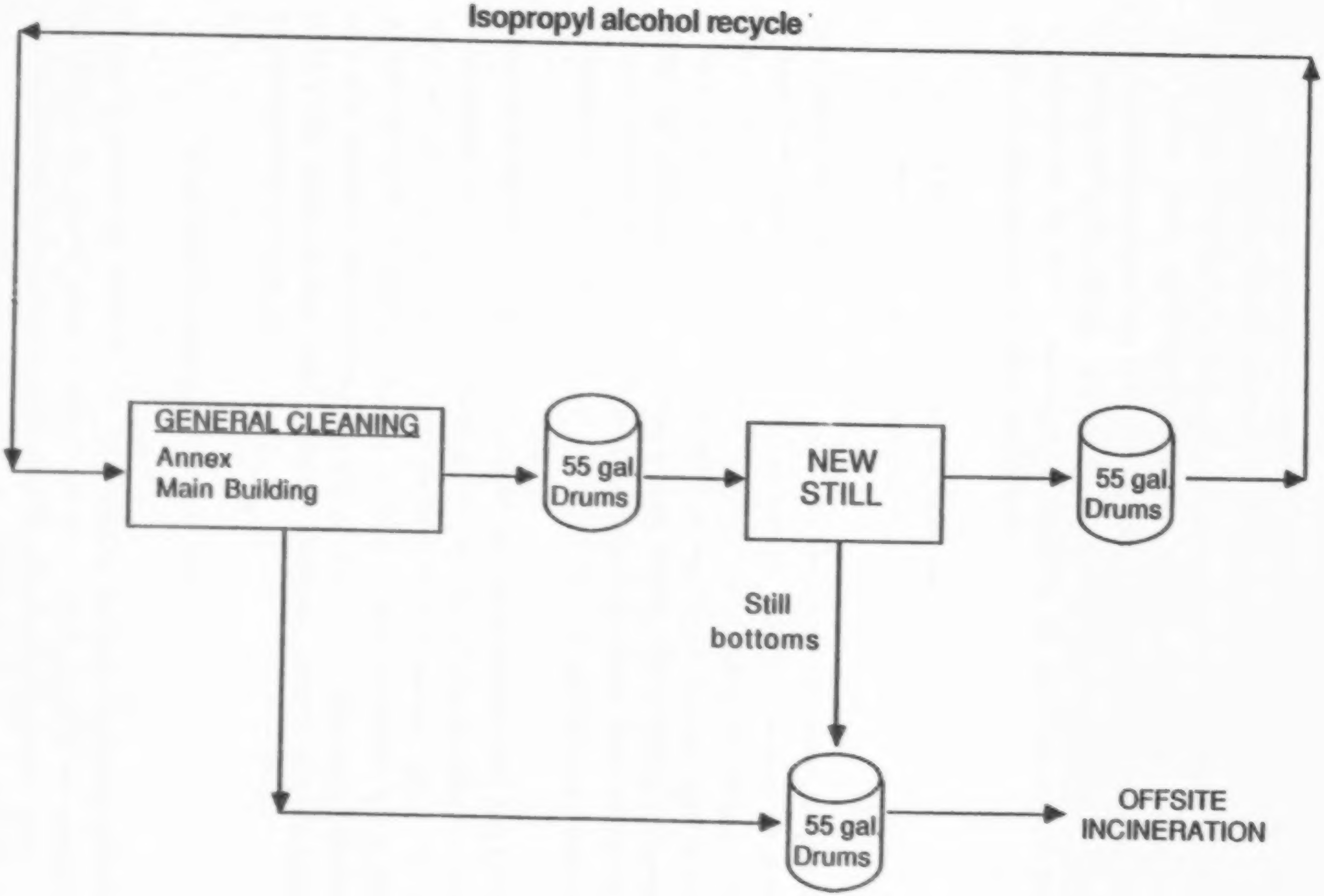

Isopropyl alcohol recycle
GENERAL CLEANING
Annex
Main Building
55 gal Drums
NEW STILL
55 gal Drums
Still bottoms
55 gal Drums
OFFSITE INCINERATION

Figure 5-3B. Proposed Isopropyl Alcohol Recovery & Recycle System

5.6.5 TCA Primary Recovery Wastes

The on-site TCA primary recovery system processes 925 gallons per week of dirty TCA. The sources of this waste include 231 gallons per week from the secondary cleaning of slurry transfer pots, 111 gallons per week from the cleaning of carriers used in the slurry application operation, and 582 gallons per week from general cleaning operations performed in the facility. Still bottoms, generated at the rate of 55 gallons per week, are sent off-site for secondary recovery of TCA. Recovered TCA is returned to the facility and used for cleaning. Of the three control options listed below, the first two are in full or partial use.

- o Wipe all pots prior to solvent cleaning.
- o Maintain the solvent's recyclability.

Contamination of solvent may be caused by the drag-in of water, solvent, or aqueous cleaner from previous cleaning operations; by improper disposal of other cleaning materials; by condensed atmospheric moisture inside piping and storage tanks; and by failure to properly maintain the distillation equipment in good working order. When undue contamination of chlorinated solvent occurs, the potential increases for the solvent breaking down and forming acid. When this occurs, time consuming measures are required to return all equipment in contact with the solvent to a usable condition.

Water entering the still can form minimum boiling azeotropes with the solvent. Since these azeotropes have a boiling point lower than that of either water or solvent alone, they will get carried over into the distilled solvent storage tank. This water can deplete the level of stabilizer (added to prevent acid formation) in the solvent. As part of a complete maintenance program, all sources of water contamination (such as leaks in the steam heating coils) should be routinely checked and the acidity of the recovered solvent monitored.

- o Install still for secondary recovery of TCA.

Of the 55 gallons per week of TCA still bottoms currently being sent off-site, only 65 percent of the solvent value is being recovered. Installation of an on-site secondary recovery system is estimated to yield over 90 percent of the solvent value.

5.7 Screening of Solvent Waste Minimization Options

Table 5-2 lists the various waste minimization options noted above for each operation. Each option has been rated on a scale of zero (low) to ten (high) for its waste reduction effectiveness, extent of current use, and future application potential. The future application potential is a qualitative measure of how difficult that option would be to implement due to technical and/or financial obstacles. After rating each option, the current and future reduction indices were determined.

Each index is computed on a scale of zero to ten with the value of ten indicating that total elimination of the waste is possible. For each operation shown in Table 5-2, the highest future reduction index has been marked by an arrow.

For wastes due to ball mill cleaning, the most effective measure would be to eliminate the use of TCA and install a recovery system for the reclamation of dirty RM-513. If the use of TCA cannot be eliminated, then proper segregation of the wastes followed by reclamation of the dirty RM-513 is indicated. For wastes due to transfer pot cleaning, slurry application system cleaning, and general cleaning, segregation and recycling of the wastes is also recommended. A cleaning solvent recycle system based on the indicated options is depicted schematically in Figures 5-3A and 5-3B.

In addition to segregation and recycling of the wastes associated with the slurry application system, the conversion of the cartridge filters to bag or metal mesh filters deserves further analysis. Further analysis also appears warranted for the secondary recovery of TCA from the waste generated by the TCA primary recovery system.

5.8 Feasibility Analysis of Selected Waste Minimization Options

Following discussions with facility personnel, several of the options described above were selected for further investigation based on their high future reduction index. Additional information was obtained from further searches of the available literature and from contact with equipment vendors. The options to be evaluated in further detail include:

- Ball Mill and Slurry Application Wastes

  Segregate and recycle RM-513 based off-spec slurry.

TABLE 5-2 SUMMARY OF SOLVENT WASTE MINIMIZATION OPTIONS FOR FACILITY S-2

Waste Source	Waste	Control Methodology	Waste Reduction Effectiveness	Extent of Current Use	Future Application Potential	Current Reduction Index	Future Reduction Index
Ball Mills	Off-Spec Slurry Mill Cleaning	1. Dedicate mills to slurry formula.	8	9	5	7	0
		2. Increase degree of quality control.	8	8	5	6	1
		3. Use two-step mill flush.	5	5	7	3	2
		4. Segregate and recycle RM-513 wastes.	6	0	8	0	5
		5. Standardize solvent used and recycle.	9	0	7	0	===> 6
Transfer Pots	Primary Cleaning	1. Wipe transfer pot before solvent use.	4	8	5	3	0
		2. Segregate, standardize, and recycle.	9	0	8	0	===> 7
	Secondary Cleaning	3. Reduce evaporative loss of solvent.	1	6	5	1	0
		4. Increase solvent cleaning efficiency.	6	8	4	5	0
Slurry Application System	Off-Spec Slurry	1. Increase degree of quality control.	8	8	5	6	1
	Feed Pot Cleaning	2. Wipe feed pot before solvent use.	4	6	7	2	1
		3. Segregate and recycle RM-513 wastes.	7	0	8	0	6
		4. Segregate, standardize, and recycle.	9	0	7	0	===> 6
	System Flushing	5. Use two-step flush sequence.	5	0	7	0	4
	Filter Changing	6. Use bag/metal mesh type filters.	7	0	7	0	5
	Carrier Cleaning	7. Reduce evaporative loss of solvent.	1	6	5	1	0
		8. Increase solvent cleaning efficiency.	6	8	4	5	0
General Cleaning	Isopropyl Alcohol	1. Segregate and recycle solvent waste.	5	0	8	0	===> 4
	111 Trichloroethane	2. Segregate and recycle solvent waste.	9	9	9	8	1
On-Site TCA Still	Still Bottoms	1. Wipe pots before solvent cleaning.	4	9	5	4	0
		2. Maintain the solvent's recyclability.	9	7	6	6	2
		3. Install a secondary recovery system.	5	0	8	0	===> 4

- Ball Mill, Transfer Pots, and Slurry Application Wastes
  - Segregate, standardize, and recycle cleaning solvents.
- Slurry Application Wastes
  - Segregate and recycle RM-513 flushing solvent.
- Slurry Application Wastes
  - Convert application system filters to bag/wire mesh type.
- General Cleaning Wastes
  - Segregate and recycle isopropyl alcohol waste.
- TCA Primary Recovery Wastes
  - Install secondary recovery system.

5.8.1 Ball Mill/Slurry Application Wastes

By segregating the off-spec slurry waste from the other wastes generated at the ball mill and slurry application operations, 20 gallons per week of RM-513 waste would be more amenable to recycling (the remaining 30 gallons per week of RM-513/TCA waste would still have to be solidified and landfilled). Segregation would require that separate storage containers be provided to the operators. Proper training of the operators to use the special storage containers should not be a problem, since the facility has recently implemented several waste segregation programs.

Once this waste is segregated, a small 55 gallon batch still could be procured for the recovery of RM-513 (a detailed description of the intended system is provided below). The cost of procuring and installing an automated still is estimated to be $25,750 (Table 5-3). Annual savings based on recovering 14.4 gallons of solvent per week and reducing waste disposal costs would amount to $6,040 (Table 5-4). This equates to a payback period of 4.3 years. Since this period exceeds the required hurdle rate of 3.0 years, procurement of a still to recycle this waste stream only cannot be justified.

The solvent recovery still considered for use is a model LS-55, manufactured by Finish Engineering Co. The following paragraphs describe various aspects of solvent reclamation and the data sheet that follow define the operational requirements of the still.

TABLE 5-3 COST OF PROCURING AND INSTALLING A SMALL STILL

EQUIPMENT	
Still (Finish LS-55, Model 2 with switch interlock), delivered cost including sales tax and freight.	$21,450
Hoist (movable A-frame with chain pull), delivered cost including sales tax.	$ 800
Total delivered cost	$22,250
INSTALLATION	
Labor Plus Supplies (50 feet of 1" pipe for cooling water and two explosion-proof conduits)	$ 3,500
Total Installed Cost	$25,750

TABLE 5-4 ECONOMIC ANALYSIS OF SEGREGATING AND RECYCLING RM-513 CLEANING WASTE

INSTALLED COSTS	
Still (see Table 3-3)	$25,750
INCREMENTAL SAVINGS, YEARLY	
Raw Materials, Solvents (a)	$ 3,710
Disposal Costs (b)	$ 3,000
Labor (c)	- $ 450
Other (Electricity, Water, and Plastic Bags for Still) (d)	- $ 220
Savings	$ 6,040
Payback Period, Years	4.3

(a) Based on saving 14.4 gal/wk of RM-513 @ $5.15/gal.
(b) Based on reducing the volume of solidified waste by 48 gal/wk. Current landfill disposal fee is $1.25/gal.
(c) Estimated at 1 hour per week @ $9.00/hr. Actual time required will be greater but this will be off-set by the reduced labor required for solidifying the waste.
(d) Based on a still operating cost of $0.30 per gallon of recovered solvent.
(e) Payback period equals total installed cost/savings. Depreciation, taxes and fees were not included in the calculation of payback period.

Stream Characteristics

Off-specification slurry consists of RM-513 and about 30 percent (by weight) suspended solids. The solids are predominantly barium titanate, various metal oxides, and some polymeric binder. The distillation process in the still can recover from 80 to 95 percent of the solvent present in the waste. For purposes of the economic analysis, a bottoms stream of 65 percent solids by weight (77 percent solvent recovery) was assumed.

Capacity and Operational Requirements

The LS-55 is operated in a batch (Rayleigh) mode, with 55 gallons charge per batch. The unit is equipped with Nylon bags supported by a metal cage to prevent bag failure due to excessive weight of the solids (175 to 230 lbs). The dirty solvent is poured into the bag and the still heated. The solvent vapors are condensed at the top of the still and gravity fed to a drum. As the heating proceeds, the solvent is boiled off from the tank contents. When the solvent recovery rate approaches zero, heating is stopped and the contents are allowed to cool off. The metal cage, with the Nylon bag containing the distillation residues, is lifted out of the still and transferred into a 55-gallon drum. The crossbar connected to the metal cage allows for the use of an overhead chain-operated hoist (included in the estimate of capital cost). A new Nylon bag is then placed in the still and the process repeated.

Utilities and Consumption Rates

The LS-55 uses electric heaters, though steam heating is available as an option. The heater uses 220V, 50-60 Hz, single phase electricity, and the coils are rated at 6.2 kW. The condensation of the solvent vapors is carried out with cooling water consumed at the rate of 1 to 1.5 gpm.

Space and Installation Requirements

The LS-55 is 56" long, 60" high, and 34" wide. The unit weighs 875 lbs when empty, and 1400 lbs when charged with dirty solvents. The installation of the unit is simple and requires connecting cooling water supply lines and electrical power (220V) to the unit.

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SOLVENT RECOVERY STILL DATASHEET

Service SOLVENT RECOVERY STILL	**PROJECT NO.** 35-7820-16 **SPEC. NO.**
	Item(s) Tag No.
For	
Site	**By** S.B. **Date** 10/28/86 **Rev. No.** 0
Manufacturer	**Approval by** **Date**
	Size and Model
	Serial No.
Bench/Pilot Test Required Yes ☒ No ☐	**No. Units Required** One

STREAM CHARACTERISTICS

Attribute	Feed		Distillate		Bottoms
	Dirty Solvent	Stripping Stream	Solvent Phase	Water Phase	
~~Flowrate, lb/hr~~ Batch, lbs	522	---	292 - 347	---	175 - 230
Component, weight %					
1. RM-513	70		100		Note(1)
2. Ceramic	30		---		
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
Temp., °F	70		80		
Pressure, psig	0		0		0
Density, lb/cu. ft	71.4		53.0		127 - 233
Viscosity, cP			0.55		
Thermal Cond.,Btu/hr-ft-°F			0.08		
Latent Heat, Btu/lb			44.5		
Spec. Heat, Btu/lb-°F			0.459		
Boiling Range, °F			210 - 215		
Toxic (Y/N)	Yes		Yes		
Corrosive (Y/N)	No		No		
Ignitable (Y/N)	Yes		Yes		No
Max. Stable Temp.,°F			855		
Steam Degradable (Y/N)	No		No		No
Other					

Note (1): Bottoms should be dry enough to pass Ignitability Tests (RCRA 40CFR 261.21).

CAPACITY AND OPERATION REQUIREMENTS

Dirty Solvent Load : 38 Lb/Shift 1 Shift/Day 5 Days/Week

Mode Of Operation : Batch (Rayleigh) ☒ Continuous ☐ Other(Explain) ☐

Still Capacity : Lb/Hr Feed ☒ Product ☐ 55 Gal. Batch

Turndown Ratio :

No. Of Stages : Theoretical 1 Actual 1 ΔP, In.WC.

Trays ☐ Type Spacing ΔP, In.WC.

Packing ☐ Type HETP, Inches ΔP, In.WC.

Reflux Ratio Design Range

HEATING MODE

Direct Steam Inj. ☐ Shell & Tube Reboiler ☐

Insert Tube Bundle ☐ Jacket ☐ Coil ☐

Electric ☒ Other (Explain) ☒ External Coil

AVAILABLE UTILITIES / CONSUMPTION RATES

Steam : Sat. ☐ Pressure Level(s), PSIG : Flow, Lb/Hr

Supht. ☐ Press., PSIG/Temp. °F : Flow, Lb/Hr

Vacuum : mm Hg Abs. Flow, ACFM

Plant Air, PSIG , SCFM Instr. Air, PSIG , SCFM

Cooling Water : Temp. In/Out, °F 70 / 110 GPM 1.0 - 1.5

Electric Power : 220 Volts 1 Phase 50 - 60 Hz 6.2 KW

Heating/Cooling Media :

SPACE / INSTALLATION / TEST REQUIREMENTS

Length 80" Height 80" Width 60"

Weight, Lbs Empty Operating

Stationary ☒ Moveable ☐

Foundations Required Yes ☐ No ☒

Field Assembly Required Yes ☐ No ☐ No. of Delivered Modules

Estimated Assembly Labor, Mhrs

Insulation Shop ☒ Field ☐

Painting Shop ☒ Field ☐

Performance Test Witnessed ☐ Nonwitnessed ☒

Hydrostatic Test Witnessed ☐ Nonwitnessed ☒

Shop Inspection Yes ☐ No ☒

INSTRUMENTATION

Piping and Instrumentation Diagram Provided Yes ☒ No ☐
Conceptual Control Schematic Provided Yes ☒ No ☐
Instrumentation Requirements Mfg Standard Acceptable ☒
Custom Requirements ☐

Automatic Control Options :
Feed Flowrate ☐ Bottoms Flowrate ☐ Condenser Temp. : Inlet ☒ Outlet ☐
Reboiler/Still Liquid Level ☐ Receiver Liquid Level ☐
Still Pressure ☐ Reflux Ratio ☐

Monitoring Options (A - Alarm ; I - Indicator; R - Recorder ; M - Multiplex)

	Liq. Level	Pressure	Temp.	Flow	Composit.
Solvent Feed					
Steam Feed					
Reboiler/Still			I		
Receiver					
Separator					
Condenser Inlet			I		
Condenser Outlet					
Clg. Wtr. Inlet				A/I	
Clg. Wtr. Outlet					
Bottoms			I		
Feed Tank					
Bottoms Tank					

Control Panel Local ☒ Remote ☐

SAFETY FEATURES

Automatic Unit Shutdown Due To :
CW Failure ☒ Low Level ☐ Other ☐
Bottoms Temperature ☒ Pressure ☐ Feed Interrupt ☐

Overpressure Protection ;
Rupture Disk(s) ☐ Relief Valve(s) ☒ Other ☐

Explosion - Proof Electricals Yes ☒ No ☐ NEMA 7, Class 1, Group D, Division 1

Grounding Protection ☒

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EQUIPMENT TO BE SUPPLIED

FEED	1. Feed Transfer Pump ☐ 2. Feed Tank ☐ Gravity Flow ☒ 3. Feed Charge Pump ☐ 4. Filter(s) ☐ 5. Strainer(s) ☐ 6. Feed Preheater ☐
STILL	7. Boiling Chamber ☒ 8. Column ☐ 9. Column Internals ☐ 10. Reflux Head ☐
DISTILLATE	11. Condenser ☒ 12. Receiver ☐ 13.Coalescer/Separator ☐ 14. Reflux Pump ☐ 15. Product Pump ☐ 16. Product Tank ☐
BOTTOMS	17. Reboiler ☐ Type : 18. Bottoms Pump ☐ 19. Bottoms Tank ☐ Removal Mode : 19. Pan ☐ 20. Liner Bag ☒ 21. Gravity Flow ☐
AUXILIARY EQUIPMENT	22. Chiller ☐ 23. Cooling Tower ☐ 24. Boiler ☐ 25. Vacuum Generator ☐ 26. Metal Cage for Bag Holding

COMPONENT DESIGN PARAMETERS

PARAMETER	Package Component Number (from above)									
	7	11	26							
Pump GPM/TDH, ft.										
Tank Capacity, gal.	55									
Dimensions /Size										
Duty, BTU/ hr										
Heat Transfer Area, sq. ft.										
TEMA Type										
Mat'l. of Construction	SS316									
Shell		SS316								
Tube		SS316								
Impeller										
Casing										
Liner										
Gaskets										
Corrosion Allowance										
Design P/T (PSIG/°F)										
Design Code										

Instrumentation and Safety Features

Finish Engineering Co. provides detailed piping and instrumentation drawings for the LS-55, along with control schematics. The electricals are explosion-proof and meet NEMA & Standards, Class I, Group D, Division 1. Internal and external grounding is provided. The LS-55 has only one temperature indicator for monitoring the temperature of the solvent vapors. The temperature of the still can be set by an adjustable temperature controller. A thermostat control scheme is employed for normal operation. Other required attachments for the LS-55 include flow switch interlock, to shut the heat input in case of cooling failure, and still high temperature shut-off with timer. The LS-55 is equipped with a safety relief valve to prevent excessive pressure buildup in the unit.

Testing Procedures

Finish Engineering provides free test runs to determine if the LS-55 is capable of meeting the degree of solvent reclamation required. A 3 to 5 gallon sample, along with the solvent data sheets can be sent to the Riverside, California office of Finish Engineering for testing. The reclaimed solvent and the distillation residues are returned after the test run. Finish Engineering does not have the capabilities to analyze the end products of the distillation run. This analysis would have to be done by the facility or by an offsite laboratory. It is highly recommended that both the distilled solvent and the bottom residues be analyzed. Bottoms must be analyzed for EP toxicity and flammability to establish whether or not they can be disposed of as non-hazardous waste. Because of the high solvent recovery rate expected and the relatively inert nature of the solids present, it is quite possible that the bottoms will pass both tests.

5.8.2 Ball Mill/Transfer Pots/Slurry Application Wastes

After segregating the wastes according to solvent type (RM-513 or TCA), efforts should be made to standardize the type of solvent used for cleaning. Figure 5-3A represents a modified block flow diagram for standardizing the type of solvent used for cleaning equipment which handles RM-513 based materials. Compared to the cleaning scheme currently employed (Figure 5-2A), the major differences would be:

- Primary ball mill rinse would use RM-513, instead of TCA.
- Primary transfer pot cleaning would use RM-513, instead of TCA.
- Slurry application pot rinsing would use RM-513, instead of TCA.

Once these changes are made, the amount of RM-513 based waste will increase so that the economic justification for procuring a still is improved. Assuming that all 50 gallons per week of waste can be converted to RM-513 based waste, annual savings of $19,130 would result (Table 5-5). This equates to a payback period of 1.3 years. Since this is much less than the required hurdle rate of 3.0 years, procurement of the still is a recommended option.

The recovered solvent could be used for the cleaning operations shown in Figure 5-3A. Virgin solvent would still be used for the ball mill secondary rinse and the slurry application system second flush. Use of virgin solvent would ensure system cleanliness and would provide solvent make-up for losses due to evaporation. Since RM-513 is a non-compliance (i.e. reactive) solvent, the facility would have to ensure that increased use of the solvent would not lead to undue increases in air emissions.

5.8.3 Slurry Application Wastes - Solvent Flush

By segregating the flushing waste from the other wastes that are sent off-site for incineration, 14.5 gallons per week of RM-513 could be recovered from this waste by use of a small batch still. The cost of procuring and installing an automated still is estimated to be $25,750 (Table 5-3). Annual savings based on recovering RM-513 and reducing waste disposal costs would amount to $5,400 (Table 5-6). This equates to a payback period of 4.8 years. Since this period exceeds the required hurdle rate of 3.0 years, procurement of a still to recycle this waste stream only cannot be justified.

5.8.4 Slurry Application Wastes - Filter Cartridges

Cartridge waste could be virtually eliminated by changing to bag style filters. Bag filters do not have a rigid structure so that they are very collapsable hence reducing disposal volume. In addition, they retain very little slurry and can hold four times as much solids as can cartridges. Assuming that the bag filters could not be cleaned and reused, their use would save the facility $1,260 per year (Table 5-7). Since all of the current filter housings would have to be changed at an estimated installed cost of

TABLE 5-5 ECONOMIC ANALYSIS OF SEGREGATING, STANDARDIZING, AND RECYCLING CLEANING WASTES

INSTALLED COSTS	
Still (see Table 3-3)	$25,750
INCREMENTAL SAVINGS, YEARLY	
Raw Materials, Solvents (a)	$10,910
Disposal Costs (b)	$ 8,870
Labor (c)	negl.
Other (Electricity, Water, and Plastic Bags for Still) (d)	- $ 650
Savings	$19,130
Payback Period, Years	1.3

(a) Based on weekly loss of 5.6 gals of RM-513 @ $5.15/gal as compared to 28.5 gals of RM-513 and 20 gals of TCA @ $4.99/gal before implementation of this option.

(b) Based on reducing the volume of solidified waste by 142 gal/wk. Current landfill disposal fee is $1.25/gal.

(c) Increase in labor associated with the operation of the still is assumed to be off-set by the reduced labor required for solidifying the waste material.

(d) Based on a still operating cost of $0.30 per gallon of recovered solvent.

(e) Payback period equals total installed cost/savings. Depreciation, taxes and fees were not included in the calculation of payback period.

TABLE 5-6 ECONOMIC ANALYSIS OF SEGREGATING AND RECYCLING RM-513 FROM FLUSHING OF THE SLURRY APPLICATION SYSTEMS

INSTALLED COSTS	
Still (see Table 3-3)	$25,750
INCREMENTAL SAVINGS, YEARLY	
Raw Materials, Solvents (a)	$ 3,710
Disposal Costs (b)	$ 2,360
Labor (c)	- $ 450
Other (Electricity, Water, and Plastic Bags for Still) (d)	- $ 220
Savings	$ 5,400
Payback Period, Years	4.8

(a) Based on saving 14.5 gal/wk of RM-513 @ $5.15/gal.

(b) Based on reducing the volume of waste sent off-site for incineration by 15 gal/wk and increasing the amount of solidified waste by 1 gal/wk. Current disposal fee are $3.23/gal (incineration) and $1.35/gal (landfilling).

(c) Estimated at 1 hour per week @ $9.00/hr. Actual time required will be greater but this will be off-set by the reduced labor required for solidifying the waste.

(d) Based on a still operating cost of $0.30 per gallon of recovered solvent.

(e) Payback period equals total installed cost/savings. Depreciation, taxes and fees were not included in the calculation of payback period.

TABLE 5-7 ECONOMIC ANALYSIS FOR CONVERTING CARTRIDGE FILTERS TO BAG FILTERS

INSTALLED COSTS	
Filter Housings (12), delivered cost including sales tax and freight	$20,950
Installation including labor and supplies	$ 3,000
Total Installed Cost	$23,950
INCREMENTAL SAVINGS, YEARLY	
Raw Materials, Solvents (a)	$ 570
Disposal Costs (b)	$ 690
Labor (c)	negl.
Other (Cartridges/Filter Bags) (d)	negl.
Savings	$ 1,260
Payback Period, Years	19.0

(a) Based on weekly loss of 2.2 gals of RM-513 @ $5.15/gal.

(b) Based on reducing the volume of solidified waste by 1.5 ft^3/wk. Current landfill disposal fee is $9.25/$ft^3$.

(c) The degree of labor associated with bag handling is assumed to be the same as that required with cartridges.

(d) Based on a current operation using 36 cartridges/week @ $3.00/cart. versus use of 9 bags/week @ $12.00/bag. Bags can hold four times as much solid as a cartridge and will not be reused.

(e) Payback period equals total installed cost/savings. Depreciation, taxes and fees were not included in the calculation of payback period.

$23,950, the resulting payback period of 19.0 years eliminates this option from consideration.

Use of a wire mesh filter cartridge was also investigated as a potential replacement for filter cartridges. A major advantage of this style of filter is that it is reusable and that no filter housing replacement would be necessary. The envisioned system would consist of replacing the current filters (4 per system) with washable wire mesh filters and adding a few valves to allow for backwashing of the filters with the solvent used for system flushing. Based on a total installed cost of $9,830 for all six systems, the annual savings would amount to $6,660 (Table 5-8). This equates to a payback period of 1.5 years, making this a viable option.

5.8.5 General Cleaning Wastes - Isopropyl Alcohol

General facility cleaning generates 94 gallons per week of dirty isopropyl alcohol (IPA). Since the overall quality of this waste is unknown, it is assumed that only 50 percent of the waste would be amenable to recycling. The remaining 50 percent (assumed to be too heavily contaminated to allow for efficient recovery), would continue to be sent off-site for incineration. Included with this waste would be the still bottoms from IPA recovery. A schematic diagram of the proposed system is shown in Figure 5-3B.

Recycling of IPA waste is estimated to save the facility $11,650 per year (Table 5-9). Based on a total installed cost of $25,750, the resulting payback period is 2.2 years. Since this is less than the required hurdle rate of 3.0 years, and since it was assumed that only 50 percent of the waste was recyclable, this option is very viable for implementation. For IPA waste that was too heavily contaminated with water to allow for recycling, drying with unslaked lime could be performed. While this would increase the amount of recyclable IPA, the effects of increased solids disposal would have to be addressed. A detailed discussion of the still is provided in Section 5.8.1 and Table 5-3.

5.8.6 TCA Primary Recovery Wastes

The facility currently generates 55 gallons per week of still bottoms from the operation of their TCA primary recovery system. This waste is sent off-site for

TABLE 5-8 ECONOMIC ANALYSIS OF CONVERTING CARTRIDGE FILTERS TO WIRE MESH FILTERS

INSTALLED COSTS	
Metal Mesh Filters (24), delivered cost including sales tax.	$3,830
Installation including labor and supplies.	$6,000
Total Installed Costs	$9,830
INCREMENTAL SAVINGS, YEARLY	
Raw Materials, Solvents (a)	$ 570
Disposal Costs (b)	$ 690
Labor (c)	negl.
Other (Cartridges) (d)	$5,400
Savings	$6,660
Payback Period, Years	1.5

(a) Based on weekly loss of 2.2 gals of RM-513 @ $5.15/gal.

(b) Based on reducing the volume of solidified waste by 1.5 ft^3/wk. Current landfill disposal fee is $9.25/$ft^3$.

(c) The degree of labor associated with filter cleaning is assumed to be the same as that required for replacing and disposing of cartridges.

(d) Based on a current operation using 36 cartridges/week @ $3.00/cartridge.

(e) Payback period equals total installed cost/savings. Depreciation, taxes and fees were not included in the calculation of payback period.

TABLE 5-9 ECONOMIC ANALYSIS OF SEGREGATING AND RECYCLING IPA FROM GENERAL CLEANING WASTES

INSTALLED COSTS	
Still (see Table 3-3)	$25,750
INCREMENTAL SAVINGS, YEARLY	
Raw Materials, Solvents (a)	$ 5,660
Disposal Costs (b)	$ 7,590
Labor (c)	- $ 900
Other (Electricity, Water, and Plastic Bags for Still) (d)	- $ 700
Savings	$11,650
Payback Period, Years	2.2

(a) Based on saving 47 gal/wk of IPA @ $2.41/gal. Assumes that only 50% of the waste IPA is recyclable.

(b) Based on reducing the volume of waste sent off-site for incineration by 47 gal/wk. Current disposal fees are $3.23/gal for incineration.

(c) Estimated at 2 hours per week @ $9.00/hr.

(d) Based on a still operating cost of $0.30 per gallon of recovered solvent.

(e) Payback period equals total installed cost/savings. Depreciation, taxes and fees were not included in the calculation of payback period.

additional recovery of TCA (estimated to be 65 percent). Use of an on-site still that could achieve a secondary recovery of 80 percent would reduce annual costs by $7,100 (Table 5-10). Based on a total installed cost of $25,750 for a still, the resulting payback period is 3.6 years. Since this exceeds the required hurdle rate of 3.0 years, procurement of a still for the recovery of this waste stream only is marginally acceptable.

In addition to the options excessive payback period, another obstacle is that there may be some problems in obtaining all of the necessary operating permits (permit costs have not been included in this analysis). Distillation bottoms are a listed RCRA waste and may pose disposal problems after November 8, 1986 if the TCA level exceeds 10,000 ppm. It is recommended that this issue be fully resolved before the secondary recovery of the still bottoms is attempted.

5.9 Summary and Discussion

Five major solvent waste producing operations were investigated during the initial audit. The five operations involved ball milling, slurry transfer pot cleaning, cleaning of the slurry application systems, general cleaning performed throughout the facility, and operation of the on-site TCA still. Waste minimization options were formulated for each operation, with the main focus placed on ways to increase the recyclability of the waste produced. These options were then tabulated and rated. From these ratings, options were selected for additional economic analysis. The results of this analysis are shown in Table 5-11.

For the ball milling operation, 5 options were discussed and 2 were selected for additional analysis. Segregating and recycling all of the RM-513 waste produced (contaminated and off-specification slurry) would reduce the amount of waste generated by 29 percent. Based on a payback period of 4.3 years, purchase of a dedicated system for recycling of this waste stream only is not a viable option.

The second option is an extension of the first one, in that it replaces the use of TCA for cleaning with RM-513. Total elimination of the TCA and full recycling of the RM-513 would reduce the amount of waste generated by 86 percent. Based on a payback period of 1.3 years, this option is very viable, provided that volatile organic

TABLE 5-10 ECONOMIC ANALYSIS OF RECYCLING TCA FROM STILL BOTTOMS

INSTALLED COSTS	
Still (see Table 3-3)	$25,750
INCREMENTAL SAVINGS, YEARLY	
Raw Materials, Solvents (a)	$ 7,690
Disposal Costs (b)	$ 910
Labor (c)	- $ 900
Other (Electricity, Water, and Plastic Bags for Still) (d)	- $ 600
Savings	$ 7,100
Payback Period, Years	3.6

(a) Based on saving 7.4 gal/wk of virgin TCA @ $4.99/gal and 33 gal/wk of recycled TCA @ $3.54/gal.

(b) Based on reducing the volume of solidified waste by 14.6 gal/wk. Current disposal fees are $1.25 gal.

(c) Estimated at 2 hours per week @ $9.00/hr.

(d) Based on a still operating cost of $0.30 per gallon of recovered solvent.

(e) Payback period equals total installed cost/savings. Depreciation, taxes and fees were not included in the calculation of payback period.

TABLE 5-11 SUMMARY OF SOLVENT WASTE MINIMIZATION OPTIONS INVESTIGATED FOR FACILITY S-2

Waste Source	Minimization Option	Waste Reduction gallons/year	Waste Reduction percent	Net Annual Savings(f)	Capital Costs	Payback Years(g)
Ball Mills and Transfer Pots	(*) Segregate and recycle RM-513 wastes.	720(a)	28.8	$6,040	$25,750	4.3
	Standardize solvent used and recycle.	2,150(a)	86.0	$19,130	$25,750	1.3
Slurry Application Systems	(*) Segregate and recycle cleaning waste.	725(c)	96.7	$5,400	$25,750	4.8
	Use bag type filters.	---	90.0(d)	$1,260	$23,950	19.0
	Use metal mesh type filters.	---	100.0(e)	$6,660	$9,830	1.5
General Cleaning With Isopropyl Alcohol	(*) Segregate and recycle cleaning waste.	2,350	50.0(d)	$11,650	$25,750	2.2
TCA Primary Recovery	(*) Install a secondary recovery system.	2,015(b)	73.3	$7,100	$25,750	3.6
All Waste Sources Shown Above	Use a common batch still for (*) methods.	5,810	54.3	$30,190	$25,750	0.9

(a) Based on waste volumes before solidification.
(b) Based on the volume of waste shipped off-site for treatment.
(c) See notes (a) and (b) above.
(d) Assumed value.
(e) Filters would be backwashed with the flush solvent so that no additional solvent would be required for cleaning.
(f) Net annual savings is the difference between the actual savings due to reduced raw material and disposal costs and the operating and maintenance costs.
(g) Payback period equals the capital cost divided by the annual savings. The payback period does not account for depreciation.

compound (VOC) emissions from the increased use of RM-513 do not affect the overall compliance status of the facility with air quality regulations.

For the slurry application systems, 6 options were discussed and 2 were selected for additional analysis. Segregating and recycling all of the RM-513 used for flushing out the systems would reduce the amount of waste generated by 97 percent. Based on a payback period of 4.8 years, procurement of a still to recycle this waste stream only is not viable.

Replacing the cartridge filters on each system with bag filters would reduce the total volume of generated waste by approximately 90 percent. Based on a payback period of 19.0 years, this option is not viable. Replacement of the cartridge filters with washable metal mesh filters would eliminate all filter waste. Based on a payback period of 1.5 years, this option is very viable. Since it is unknown if the wire mesh filters would perform adequately in this service, this option should be tested on a trial basis with one system.

For general cleaning operations, one option was discussed and analyzed. Segregating and recycling 50 percent of the isopropyl alcohol waste generated in the facility would result in a payback period of 2.2 years. This option is very viable since the actual amount of recyclable waste is believed to be much greater than 50 percent.

Secondary recovery of TCA from still bottoms is expected to reduce the volume of this waste by 73 percent. Based on a payback period of 3.6 years and the uncertainty regarding permit (RCRA) availability, this option does not appear to be viable.

Many of the options discussed above rely on the use of a small batch still for solvent recovery. Since the still operates in a batch mode, all of these waste streams can be separately processed in the same unit. Based on pro-rating the capital cost for one system to the savings due to implementation of the four options indicated in Table 5-11, the overall payback period would be 0.9 years. This is opposed to individual payback periods ranging from 2.2 to 4.8 years. In summary, the economic and technical feasibility for on-site solvent reclamation is well established.

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